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MACHINE RECOGNITION OF HAND-SENT MORSE CODE USING THE PDP-12 COMPUTER

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December 1973

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MACHINE RECOGNITION OF HAND-SENT MORSE CODE USING THE PDP-12 COMPUTER

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by
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Preface

This thesis is the result of an effort to provide real-time machine recognition of hand-sent Morse code through the use of a minicomputer. While the capability to recognize hand-sent Morse code messages by machine has been demonstrated before on large scale special purpose computers, the main contribution of this study was to do it with a relatively inexpensive general purpose minicomputer.

I wish to express my gratitude to my advisor, Lt. Col. Tom Purnhagen, for his assistance and guidance throughout the development of this study. I wish also to express my thanks to Captain Joseph Carl, of the Aerospace Medical Research Laboratory, for his appreciated support of this project as my laboratory sponsor, and to the Dayton Amateur Radio Association for their assistance in obtaining Morse code transmissions for use in this project. Special thanks are reserved for my wife and family for their sacrifices and patience while I spent my evenings conversing with the computer.

Joel A. Guenther

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Abstract

The purpose of this investigation is to determine an optimum decision algorithm for use in machine recognition of hand-sent Morse code. An extensive analysis of hand-sent Morse code data is presented together with a discussion on the relative merits of several recognition algorithms. A recognition program is developed for use on the PDP-12 digital computer to test these algorithms. Test results are presented for a time duration averaging algorithm which achieves less than a one per cent recognition error rate for noise-free Morse code signals.

MACHINE RECOGNITION OF HAND-SENT MORSE CODE USING THE PDP-12 COMPUTER

I. Introduction

The idea of machine recognition of Morse code is not a new one. Much work has been done to develop equipment for the automatic reception of Morse code signals in the last two decades. The first notable effort was undertaken by Lincoln Laboratories at the Massachusetts Institute of Technology in the late 1950s (Ref 4). The machine which resulted from this project was actually a special purpose digital computer, called MAUDE (Morse AUtomatic DEcoder). The recognition algorithm used in MAUDE was based on its "knowledge" of Morse code linguistic properties and of the relative time durations of marks (referred to as pulses throughout this report) and spaces. MAUDE demonstrated a 90 to 95 per cent correct decoding rate, although this rate was later improved by the addition of an output error detection and correction scheme. The main disadvantage of MAUDE, however, was its physical size and complexity.

The development of small, low-cost integrated circuits led to the design and fabrication of several Morse-to-teletype converters. Generally speaking, much simpler code recognition algorithms, as compared to those used in MAUDE, were used in these converters to identify pulses and spaces. One such converter, designed at the Naval Postgraduate School in 1968 (Ref 6), uses the time duration of the most recently received short pulse (DOT) as a reference unit for pulse and space identification. Multiples of this reference unit are used as decision thresholds to identify succeeding pulses and spaces, and to eliminate signal noise. Another

example of this type of converter, called the Morse-A-Verter, uses a variation of the previous recognition algorithm to make pulse-space decisions (Ref 5). The time duration of the most recently processed pulse, short or long, is used to determine the classification of the succeeding pulse. Spaces are identified by comparison with the time duration of tne most recent long pulse (DASH).

Morse code recognition machines perform five basic functions. First, the pulse-modulated audio Morse signal is converted into a form usable by the machine, usually dc pulses, while discriminating against noise. Second, the time duration and identification of each pulse and space is determined. Third, pulses and spaces are classified into one of two pulse or three space categories according to their relative time duration. Fourth, the categorized pulses and spaces are combined to form Morse code characters. Finally, a signal representing the identified Morse code character is transmitted to an output device.

The third function, that of categorizing pulses and spaces, is the most difficult to perform. This difficulty is mainly due to the inherently non-uniform pulse and space time durations of hand-sent code. Since these time durations form the basis for the recognition process, a rigid set of decision algorithms, such as those used in commercial Morse telegraphy equipment, cannot be used. Instead, algorithms based on traits common to all variations of hand-sent Morse code must be used to achieve the highest possible degree of machine recognition accuracy.

The objective of this study is two fold: first, to conduct a thorough examination of hand-sent Morse code data and identify common traits which may be used in a machine recognition process, and second, to develop a Morse code recognition program, for use on the PDP-12 digital

computer, to test and refine decision algorithms based on these common traits. Thus, the main concern here is optimization of the third function performed by Morse code recognition machines, as previously defined. Of course, all five functions must be considered in the development of the PDP-12 computer program. The remaining four functions, however, are of secondary concern to this project.

A discussion on the properties of hand-sent Morse code, and on the primary factors responsible for the variations present in hand-sent Morse code, is presented in Chapter II. Chapter III describes the procedure used to obtain and analyze Morse code data, and the common traits discovered during and the decision algorithms derived from this analysis procedure. A complete description of the resulting computer recognition program is presented in Chapter IV, as well as a brief description of the PDP-12 computer and peripheral devices used in this project. The operational procedure used with the recognition program is described in Chapter V. Chapter VI presents an analysis of the results obtained during the testing procedure. Conclusions and recommendations are contained in Chapter VII.

II. Properties of Hand-Sent Morse Code

This chapter presents a discussion on the characteristic properties of hand-sent Morse code. This discussion includes a definition of international Morse code, a description of common mechanical devices used to transmit Morse code, and the problems associated with machine recognition of hand-sent Morse code.

International Morse Code

Morse code is a rudimentary one-dimensional binary encoding scheme for language in which each character is represented by a unique sequence of pulses and spaces. These characters represent letters, numbers, punctuation signs, and special symbols. The international Morse code alphabet is given in Appendix C.

Two types of pulses and three types of spaces, distinguished by their relative time durations, are used to define Morse code characters. In terms of time units, the accepted standard definitions for these pulses and spaces are: pulses- DOT = 1 and DASH = 3; spaces- SYMBOL = 1, CHARACTER = 3, and WORD = 5 to 7. Characters are defined by a sequence of pulses separated by spaces. SYMBOL spaces separate pulses within a character, CHARACTER spaces separate characters within words, and WORD spaces separate words.

Morse code transmission speed is measured in terms of words per minute (wpm), with an average of 5 characters per word assumed as standard. Transmission rates for hand-sent Morse code are normally in the 10 to 40 wpm range, although rates as high as 60 wpm are not uncommon. Morse code machines are capable of operating at much faster rates, but generally do not unless another machine is used to receive the transmitted message.

Code Sending Instruments

Morse code is transmitted by keying an oscillator tuned to the desired transmission frequency or subharmonic of this frequency. The four standard instruments (keys) used to generate Morse code are, in ascending order of sophistication: 1) the simple hand key, 2) the semiautomatic key, or "bug", 3) the electronic keyer, and 4) the fully automatic Morse machine. A brief description of each instrument is presented in the following paragraphs.

The hand key, because of its simplicity and low cost, is most often used. Pulses are transmitted by depressing a paddle key; spaces are produced by lifting the key. The relative time duration in either position determines the type of pulse or space transmitted. The durations of all pulses and spaces are controlled directly by the sender.

The semiautomatic key, or "bug", is more difficult to operate and is generally used by the more experienced operator. Two paddle keys are used, one for DOTs and one for DASHes. The DOT key is used to produce a machinelike sequence of alternating DOTs and SYMBOL spaces for as long as the key is depressed. The DASH key produces DASHes in the same manual fashion as is done on the hand key.

The electronic keyer produces regulated DOTs, DASHes, and SYMBOL spaces. Two paddle keys are again used, one for DOTs and one for DASHes. Either key generates a sequence of pulses and SYMBOL spaces for as long as it is depressed. CHARACTER and WORD spaces, however, are still controlled manually. The time durations of automatically generated pulses and spaces can be adjusted to match the sending rate of the particular transmission.

Fully automatic Morse machines regulate the time durations of all

pulses and spaces. Messages are prepared ahead of time on paper tape or stored in a memory device for transmission by the machine. The transmission and reception of completely automatic Morse code is not of concern in this project.

Characteristics of Hand-Sent Morse Code

The time duration standards for Morse code pulse and space relationships presented earlier are not always realized in hand-sent transmissions. Commonly encountered distortions include fluctuating pulse and space time duration ratios and variations in sending speed. In hand-sent Morse code, the time durations of pulse and space elements vary substantially from their prescribed values, and recognition must be based on the proportions of the time durations of these elements. These proportions generally vary non-trivially.

In a 1968 report on Morse code teaching methods (Ref 8), it was noted that the chief type of code reception error arises from the tendency to hear code signals shorter than they really are. For example, five DOTs are heard as four, four DOTs as three, etc. The tendency toward "signal shrinkage" mainly involves the last element of a code character. The report further states that this tendency to hear signals shorter than they are may be responsible for the general tendency for all operators to lengthen terminal DASHes. Also noted was the tendency of operators at all levels of skill to make pulse and space time duration ratios larger than the theoretical 1:3:7 ratios. However, a better set of ratios could not be recommended since actual ratios varied widely between individual operators.

Transmission rates generally tend to decrease over an extended period of time. This is mainly due to physical as well as mental fatigue.

Pulse and space ratios also tend to change as the transmission rate decreases. The amount of ratio change varies from sender to sender, and is partly a function of the type of sending unit being used. When hand keys are used, slower transmission rates generally result in longer pulses and spaces, with spaces tending to lengthen proportionately more than pulses. The use of semiautomatic keys prevents the automatically generated pulses and spaces from being affected by speed variations. Only those output functions controlled by the operator are subject to change. Thus, the degree of ratio change due to speed change may be significantly different when semiautomatic keys are used than when hand keys are used.

The recognition algorithms used in the machines discussed earlier may not be optimal. The prospects for the useful application of linguistic techniques directly to binarised hand-sent Morse code do not appear to be good because of the non-trivial variation of element proportions (Ref 7:254). Decisions made strictly on an element-to-element basis may not be flexible enough to cope with the widely varying proportions found in hand-sent transmissions.

These variations in hand-sent Morse code transmissions are the crux of the machine recognition problem. Code recognition machine performance ultimately depends on the algorithms used to identify individual pulse and space characters. Many algorithms that work well with certain Morse signals perform miserably with others. An algorithm is needed that can correctly identify pulse and space characters for all possible hand-sent Morse code variations.

III. Data Analysis Procedure

Many possible decision algorithms may be used to recognize hand-sent Morse code by machine. Indeed, each of the three recognition machines discussed in Chapter I employs a different method to perform the recognition process. Since there was no intuitively "best" method to use in performing this process, a thorough data analysis procedure was undertaken in search for an "optimal" decision algorithm, i.e., one that would yield the smallest percentage of recognition errors for all types of Morse code transmissions. The procedures used to obtain and analyze hand-sent Morse code data and the decision algorithms derived from this analysis are presented in the following paragraphs.

Data Gathering

Three samples of Morse code transmissions were recorded for analysis. These samples differ from each other in two ways: 1) the type of sending unit used, and 2) the degree of operator proficiency. The first sample, Recording Session 1, was transmitted with a "bug" at a rate of approximately 15 words per minute. Recording Session 2 was transmitted with a hand key at a rate of approximately 10-12 words per minute. Recording Session 3 was transmitted with a "bug" at a rate of approximately 18-20 words per minute. The three recording sessions were transmitted by separate individuals at their normal speed. None of these individuals were, at the time of the recordings, actively involved in cw (continuous wave) transmissions as a hobby, although they were at some time in their past. Thus, the recordings, are biased towards a low-proficiency level. As pointed out in the next section, this resulted in a slightly erratic sending rate and a wide spread of pulse and space time durations over a given time period.

The recording sessions were conducted in the following manner. A 500-word text, taken from The Radio Amateur's Handbook (Ref 1:7), was prepared for use as the message to be transmitted. A copy of this message, listed in Appendix D, was given to each of three individuals. While one individual transmitted the message, the other two annotated observed sending errors on their copy of the text. The Morse code transmission was recorded for use in the data analysis process. Only one recording session was held at a time to prevent mental fatigue from adversely affecting both the sender and the receivers. Recording sessions were held every other day until complete. The annotated copies of the transmitted Morse code messages were saved for use in evaluating recognition program performance, as explained in Chapter VI.

Data Categorizing

The recorded hand-sent Morse code transmissions were examined in a three step process. First, the time durations of pulses and spaces were obtained and stored on magnetic computer tape. Second, each pulse and space was identified as belonging to one of twenty different categories and again stored on magnetic tape. Finally, the categorized pulses and spaces were plotted for visual examination. Each of these three steps will now be discussed.

Analog-to-Digital Conversion. The time duration for each transmitted pulse and space was obtained and stored through the use of the PDP-12 computer in the following manner. The recorded Morse code transmission was connected to an A-D Converter external input channel and sampled periodically. When a change was detected, i.e., pulse-to-space or space-to-pulse, the time duration indicated on a real-time clock was recorded

and stored. The clock was then reset and the process repeated.

Approximately the first 200 words of each 500-word Morse code transmission were processed in this manner. Upon completion of this process, the stored time durations were visually examined and categorized, as explained next.

Manual Identification. Pulses and spaces were classified into 10 separate categories each. Space categories were chosen to permit investigation of the pulse vs. following space interrelations known to exist in hand-sent Morse code. For example, the time duration of a space, when preceded by a DASH, is generally less than it is when preceded by a DOT. Thus, space categories correspond directly to the category of the preceding pulse. Pulses were separated into five DOT and five DASH categories according to their relative position within a Morse code character. In this way, time duration vs. position interrelationships, if any, would be disclosed. The 20 pulse and space categories are listed in Table I.

TABLE I

Pulse and Space Categories

1.	DOT (Only)	11.	DASH (Only)
2.	Space following 1.	12.	Space following 11.
3.	DOT (First)	13.	DASH (First)
4.	Space following 3.	14.	Space following 13.
5.	DOT (Intermediate)	15.	DASH (Intermediate)
6.	Space following 5.	16.	Space following 15.
7.	DOT (Last Character)	17.	DASH (Last Character)
8.	Space following 7.	18.	Space following 17.
9.	DOT (Last Word)	19.	DASH (Last Word)
10.	Space following 9.	20.	Space following 19.

The Only category identifies a DOT or DASH that by itself signifies a Morse code character (the characters E and T respectively). A pulse is First if it is the first pulse of at least two pulses comprising a character. Likewise, a pulse is Last if it appears as the last pulse in the character. The Last Character and Last Word categories are determined by the type of space following the pulse, i.e., CHARACTER space or WORD space. An Intermediate pulse is one which is neither first nor last in a multi-pulse string. Only category pulses which also appear as the last pulse in a word are categorized as Last Word.

The visual identification process was performed in the following manner. Stored pulse and space time durations were displayed on the PDP-12 CRT Display screen as a series of lines, proportionate in length to the time duration represented, as depicted in Fig. 3-1. A cursor was also displayed to indicate the particular pulse to be categorized. Note that it is only necessary to identify pulses, since spaces are categorized by the type of preceeding pulse. The pulse was then visually identified by noting its relative length and position with respect to surrounding pulses and spaces. The pulse and following space time durations were then stored according to their respective categories by depressing one

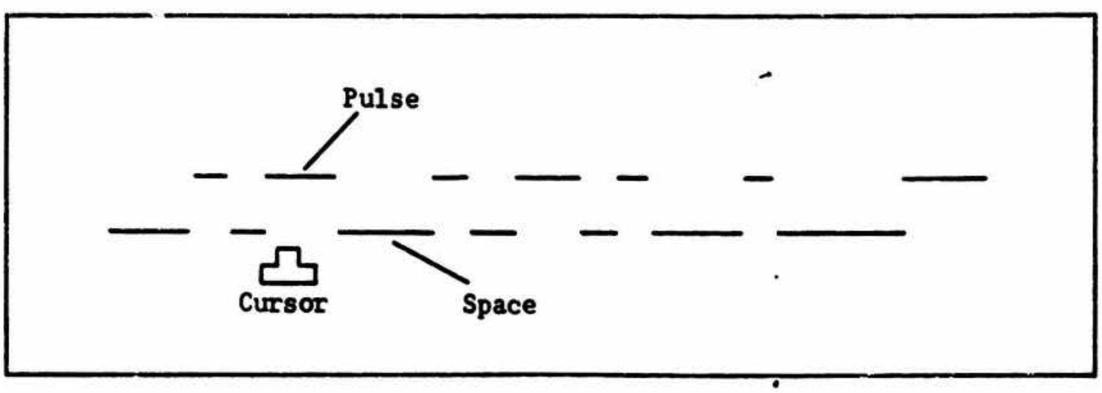


Fig. 3-1. CRT Morse Code Display

of 10 keys on a teletypewriter. Depression of the teletype key also advanced the display to the next pulse to be identified. The process was continued in this manner until all pulses and spaces were categorized and stored.

Distribution Plots. Cluster-type distribution plots of the categorized pulses and spaces were obtained by plotting pulse time duration versus following space time duration for the 10 categories. Plots were made of each individual category as well as all categories combined for the three recording sessions. The individual category plots for Recording Session 1 and combined plots for all recording sessions are contained in Appendix B, Figures B-1 through B-13.

Data Analysis

The individual and combined distribution cluster plots for the three recording sessions were examined to identify any possible relationships that might be used in the recognition program. Several such relationships were found.

It was immediately obvious that some of the pulse and following space categories are essentially identical and can be combined into one unique category. The First and Intermediate categories for both DOTs and DASHes are identical, as are the Only and Last Character categories. Thus, the 10 original categories can be reduced to 6 categories, 3 for each type of pulse. These three categories correspond to the type of following space, i.e., SYMBOL, CHARACTER, and WORD.

Another obvious trait disclosed by the data plots was the large variance of CHARACTER and WORD space time durations. Since the plots represent data obtained over an extended period of time (approximately

10-15 minutes) it was thought possible that the large variance was due to a gradual change in transmission speed during the time interval. To investigate this possibility, plots of pulse and space durations versus their sending sequence in time were made for the DASH Intermediate, Last Character, and Last Word categories. These plots, two of which are included in Appendix B (Figures B-14 and B-15), indicate that the large variance is not a function of a general speeding-up or slowing-down trend, but is, in fact, a characteristic of hand-sent Morse code.

Examination of the data plots for all categories combined indicates that a large overlap exists between CHARACTER space and WORD space time durations. The existance of this overlap prohibits correct identification of CHARACTER spaces versus WORD spaces on a time duration threshold basis. However, this distinction is not a critically important one, since both types of spaces signify the end of a Morse code character. The combined category data plots do, however, indicate a wide gap between SYMBOL space and non-SYMBOL space clusters. These gaps lend themselves to the formation of linear decision boundaries in two-dimensional pattern space quite easily.

Another obvious condition revealed by the combined data plots is the wide gap between DOT and DASH time durations. This again is conducive to a linear decision technique.

The combined data plots reveal two distinct correlations between DASH time durations and the type of following space. The first, and most obvious of the two is that DASH time durations are generally longer when followed by a CHARACTER or WORD space than they are when followed by a SYMBOL space. The second correlation is that SYMBOL space durations tend to decrease as the time duration of the preceding DASH increases,

and vice versa. Neither of these pulse-space correlations are evident in the DOT-space categories.

As discussed earlier in Chapters I and III, several different types of decision algorithms have been successfully used to recognize hand-sent Morse code. Most notable among these are the use of a unique set of linguistic rules and the comparison of the time duration of the previous pulse with that of the next space and pulse on a threshold decision basis. A different approach to the recognition problem was looked for in this project; one that might prove more successful than those methods previously tried.

Evaluation of all the observations made from the data distribution plots led to the derivation of pulse and space linear decision algorithms, based on time duration averages, for use in the recognition program. These algorithms are discussed in the following paragraphs.

Pulse Algorithms. Due to the wide separation between DOT and DASH time durations, and the small variance of these durations, a linear decision boundary can easily be established as a function of DOT and DASH averages. However, to allow for slowly changing transmission rates, and to suppress temporarily large excursions from the mean, individual DOT and DASH averages must be calculated on a floating basis. That is, the averages must be computed for the last N DOTs and DASHes received, rather than on all received since the start of Morse code processing. The optimum size of N is that which both suppresses large excursions and permits the average to follow slowly varying changes. A value of eight achieves these goals and, as discussed below, permits easy average computation on the PDP-12 computer.

The DOT average is computed by the following equation:

$$\text{DOT AVG.} = \text{DOT AVG.} + \frac{\text{NEW DOT}}{8} - \frac{\text{DOT AVG.}}{8} \qquad (3.1)$$

When a newly received pulse is identified as a DOT, the DOT average is recomputed to include the new time duration information. The division process is performed by shifting the 12-bit register, containing the quantity to be divided, three places to the right. This is the equivalent of dividing the quantity by 2^3 or 8. The use of this process eliminates the time consuming task of adding 8 registers together and then dividing by 8. The DASH average is computed in the same manner as the DOT average.

The pulse average is computed after each recomputation of either the DOT average or the DASH average by the following equation:

$$\text{PULSE AVG.} = \frac{\text{DOT AVG.}}{4} + \frac{\text{DASH AVG.}}{2} \qquad (3.2)$$

The pulse average is used as the pulse time duration linear decision boundary. Note that the pulse average is not the mean of the DOT and DASH averages, but is instead, slightly closer to the DOT average. This adjustment compensates for the difference between DOT and DASH time duration variances. The resulting pulse decision boundary lies nearly in the center of the gap between DOT and DASH time duration clusters. If a new pulse has a time duration greater than the pulse average, it is considered to be a DASH; otherwise it is a DOT. Recomputation of the pulse average after receipt of each DOT and DASH permits the threshold

to adjust to slowly varying changes as they occur.

The DOT and DASH averages are influenced most by the DOT-SYMBOL and DASH-SYMBOL clusters shown on the data distribution plots. This is due to the fact that there are proportionately more pulses followed by SYMBOL spaces than followed by CHARACTER or WORD spaces. Since the DOT and DASH time duration variance is smaller in these clusters, especially in the DASH-SYMBOL cluster, the resulting pulse average, as determined by equation (3.2), lies more near the center of the gap between the two clusters, thereby providing a better linear decision boundary.

Space Algorithms. The wide variance of CHARACTER and WORD space time durations prohibits use of the averaging technique used for the pulse algorithms. The technique was tried, however, with less than desirable results. A threshold was established as the mid-point between the CHARACTER space average and the WORD space average. New spaces were classified as CHARACTER spaces if their time duration was less than the threshold, and as WORD spaces if their time duration was greater than the threshold. Respective space averages were then computed in a manner similar to that used in the pulse algorithm. In test runs of the recognition program, the threshold point was consistently smaller than the optimum value, resulting in many CHARACTER spaces being classified as WORD spaces.

This lower than desired threshold is due to two contributing factors. The first, and most important, is the large overlap of the CHARACTER and WORD space variances. The second factor is the difference in frequency of occurrence of the two types of spaces. CHARACTER spaces, for English language text, occur approximately 4 times as often as WORD spaces. Those CHARACTER space time durations which are slightly greater than the

threshold value force the WORD space average to be lower than it actually is. This, in turn, lowers the threshold value, which is defined as the mid-point of the CHARACTER and WORD space averages. The lower threshold causes more CHARACTER spaces to be defined as WORD spaces, thus lowering the WORD space average even more and compounding the problem. The threshold value settles near the true CHARACTER space average, much lower than desired.

The space algorithm finally arrived at for use in the recognition program is based on the average of all non-SYMBOL spaces which follow a DOT. The CHARACTER-WORD space average is calculated as follows:

$$\text{C-W SPACE AVG.} = \text{C-W SPACE AVG.} - \frac{\text{C-W SPACE AVG.}}{8} + \frac{\text{SPACE TIME}}{8} \quad (3.3)$$

Figures 3-2, 3-3, and 3-4 illustrate the linear decision boundaries, as determined by the pulse and space algorithms, for Recording Sessions 1, 2, and 3, respectively. Individual pulse-space clusters have been circled on these figures to indicate the size and shape of each cluster and the overlap regions between clusters. Table II lists the type of cluster identified by the letters shown on the three figures.

TABLE II

Cluster Identification for Figures 3-2, 3-3, and 3-4

Area	Cluster Type
A	DOT-WORD
B	DOT-CHARACTER
C	DOT-SYMBOL
D	DASH-WORD
E	DASH-CHARACTER
F	DASH-SYMBOL

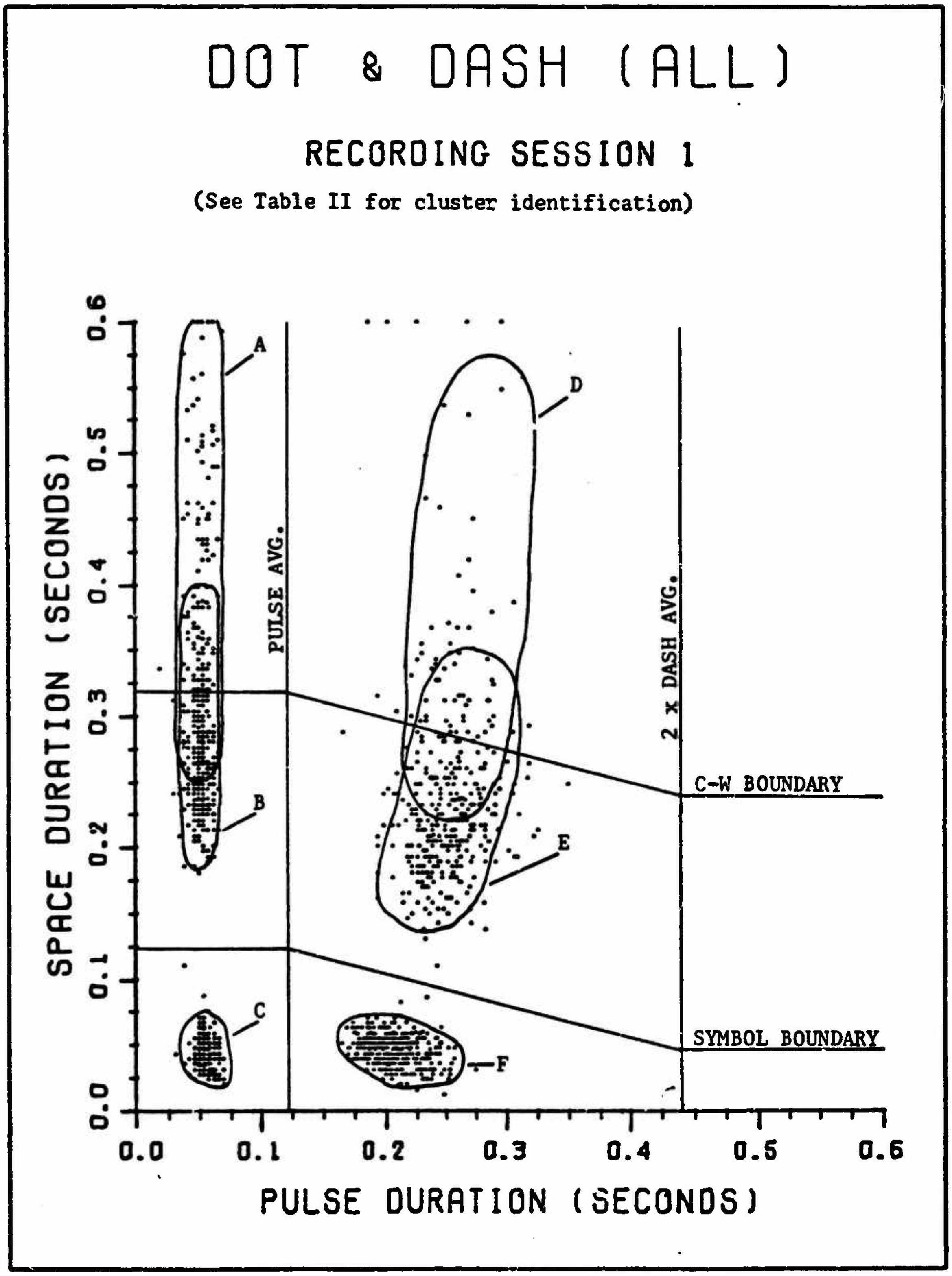


Fig. 3-2. Linear Decision Boundaries for Recording Session 1.

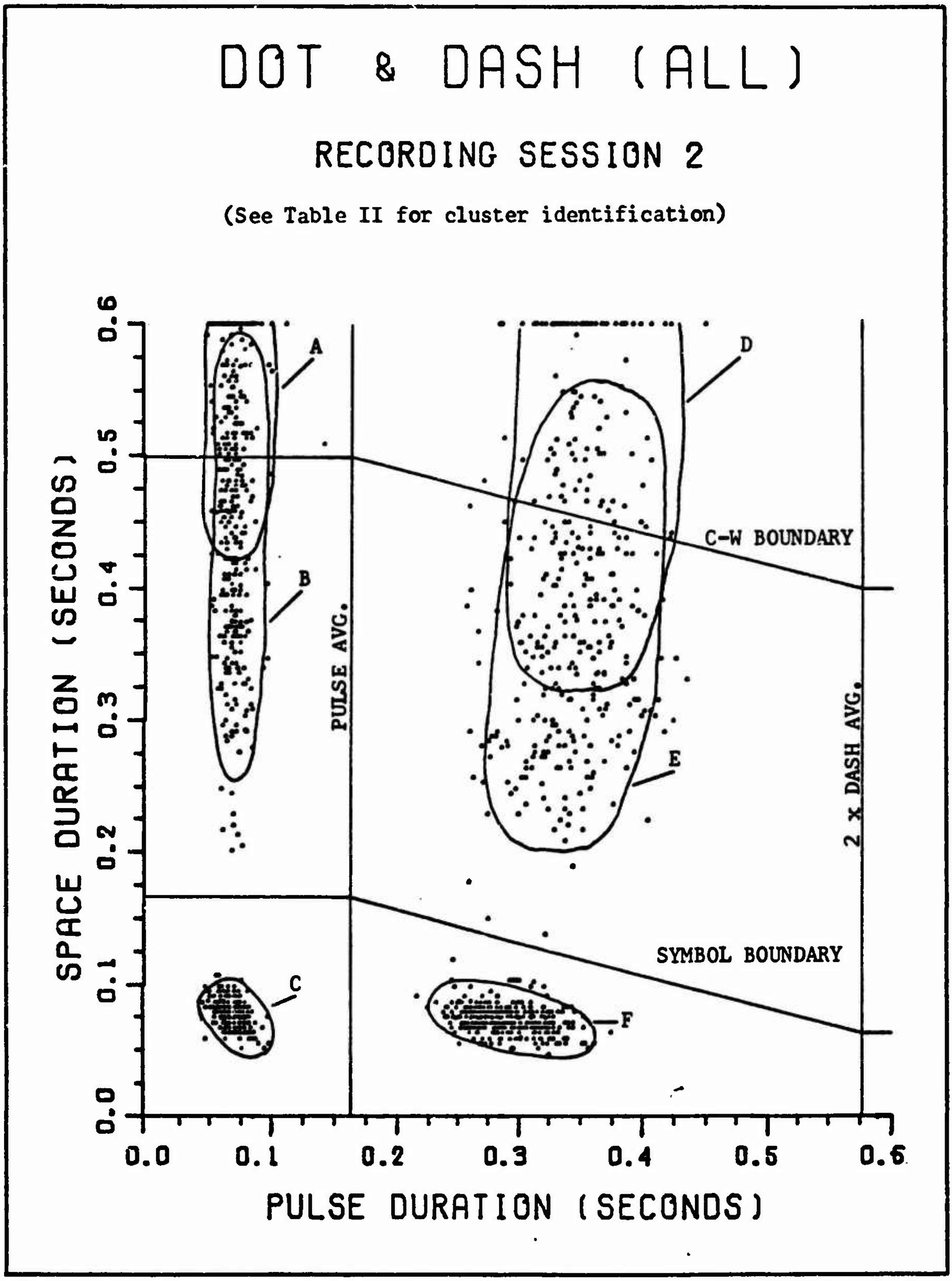


Fig. 3-3. Linear Decision Boundaries for Recording Session 2.

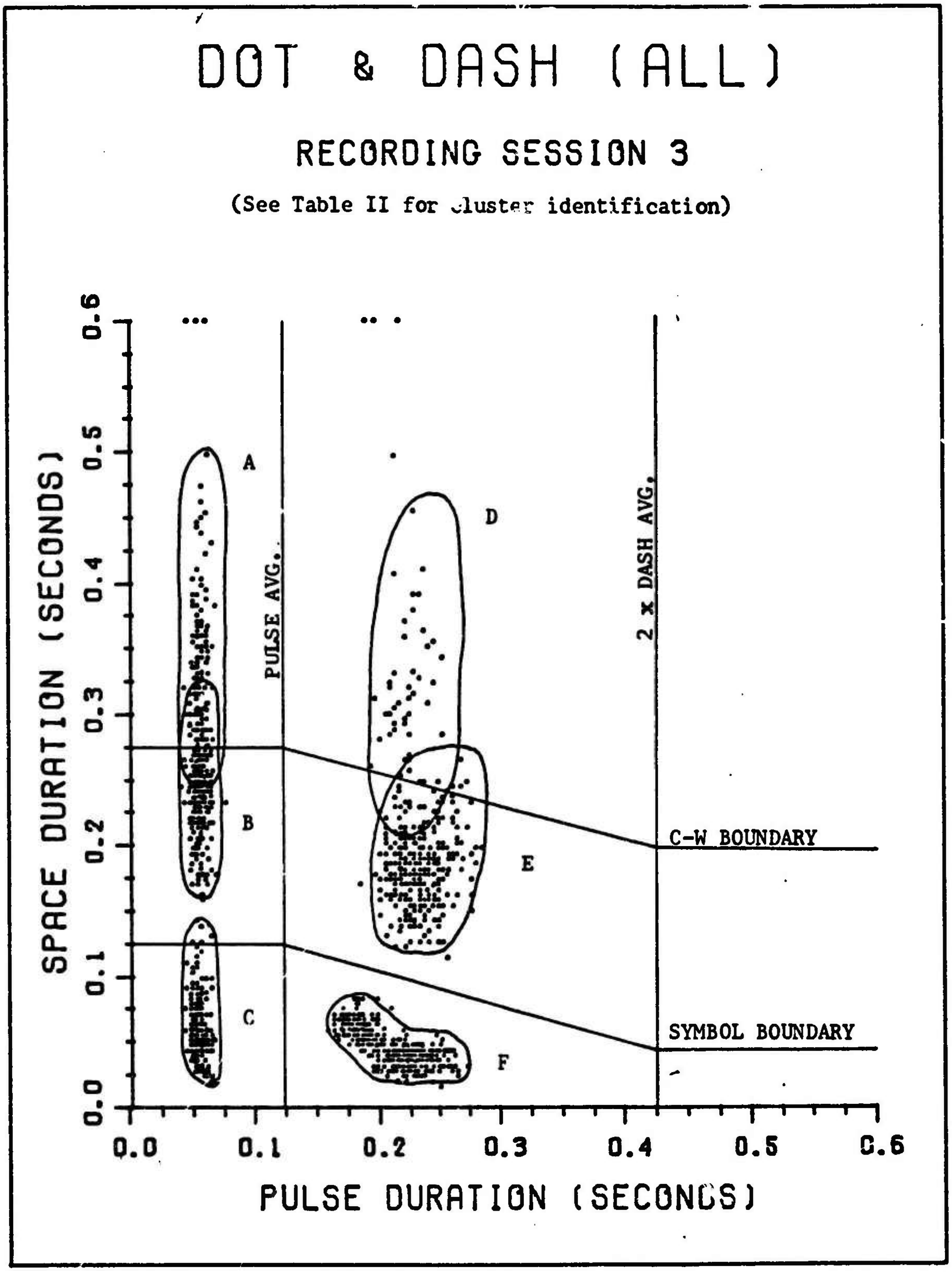


Fig. 3-4. Linear Decision Boundaries for Recording Session 3.

The pulse average lies in the gap between the DOT and DASH clusters on all three figures. This average value also lies in the gap between the DOT-SYMBOL cluster and the DOT-CHARACTER cluster for Recording Sessions 1 and 2, but not for Recording Session 3. Notice that the DOT-SYMBOL cluster in Fig. 3-4 has a much larger SYMBOL space variance than is indicated on similar clusters shown in Figures 3-2 and 3-3. This large variance is due to a faulty DOT-SYMBOL space generator on the "bug" used to transmit Recording Session 3. Therefore, it is assumed that the pulse average value also lies in the correct location for Recording Session 3. The pulse average is therefore used as the linear decision boundary for SYMBOL versus non-SYMBOL space decisions, when the space is preceded by a DOT. Also notice that the CHARACTER-WORD average, computed by equation (3.3), lies in the DOT-CHARACTER and DOT-WORD cluster overlap region.

CHARACTER and WORD spaces, when preceded by a DASH, have shorter time durations than those preceded by a DOT. Therefore, an adjusted boundary value must be used when a space is preceded by a DASH. The adjusted SYMBOL space boundary value is computed as a function of the time duration of the preceding DASH as follows:

$$\text{SYMBOL BOUNDARY} = \text{PULSE AVG.} - \frac{(\text{DASH TIME} - \text{PULSE AVG.})}{4} \qquad (3.4)$$

The adjusted CHARACTER-WORD space boundary value is computed in a similar manner as follows:

$$\text{C-W BOUNDARY} = \text{C-W SPACE AVG.} - \frac{(\text{DASH TIME} - \text{C-W SPACE AVG.})}{4} \qquad (3.5)$$

The resulting linear decision boundaries are negatively sloping lines, as shown on the accompanying figures. A maximum DASH time duration is established as twice the current DASH average for use in the boundary computations, thereby setting a lower limit to the threshold value.

To permit real-time adjustment of the C-W Boundary, a positive or negative adjustment value, X, is added to the threshold as follows:

$$\text{ADJUSTED C-W BOUNDARY} = \text{C-W BOUNDARY} \pm X \qquad (3.6)$$

By adding the appropriate adjustment value to suit a particular Morse code transmission, the operator can optimize the readability of the printed output.

IV. The Computer Recognition Program

This Chapter describes the operation of the computer recognition program. The program consists of two distinct but interdependent parts: 1) the Signal Processor section, and 2) the Code Translation section. Discussion of the routines contained within each section is presented in an order indicative of the overall organization of the recognition program and the sequence in which the routines are executed. General flow charts are included for each routine to supplement the associated text.

A discussion of the programming constraints due to the physical limitations of the PDP-12 computer and the self-imposed operational goals is presented at the beginning of this chapter. It is hoped that knowledge of these limitations will enable the reader to better understand the rationale behind various operations performed within the program. A complete program listing with comments is provided in Appendix A.

Program Constraints

Before ideas can be constructively transformed into computer programs, the operational characteristics of the particular computer system to be used must be defined. A list of operational goals and performance objectives must also be defined to optimize the programming process.

PDP-12 Description. A brief overview of the characteristics of the DEC (Digital Equipment Corporation) PDP-12 (Programmed Data Processor-12) computer is provided in this section. A more complete description of the PDP-12 may be obtained in the PDP-12 System Reference Manual (Ref 2).

The PDP-12 is a versatile digital computer which contains two distinct

operating modes within its central processor, each with its own instruction set. The central processor logic is fully parallel, using a basic word length of 12 bits. The processor cycle time is 1.6 microseconds $\pm 20\%$. Most instructions require from 1 to 3 cycles for execution. The PDP-12 operates in one mode as a LINC (Laboratory Instrument Computer) and in the other mode as a PDP-8 computer. The computer may be stopped and started in either mode. Both operating modes have equal priority and programs may be switched from one to the other at will. Computations in one mode are immediately available to programs operating in the other mode because only one set of processing registers is involved.

The principal unit of core memory is a module of 4096 (4K) 12-bit words. Up to seven additional modules may be added, providing a total of 32,768 words. The logical organization within each module depends on the operating mode. In LINC mode, each 4K module is divided into four 1024-word segments. Only two of these segments are active at any given time: 1) the Instruction Field, which contains the executable program and directly addressed data, and 2) the Data Field, which contains only indirectly accessed data. In 8 mode, each 4K module (memory field) is divided into thirty-two 128-word pages. Data may be directly addressed to the current page or to page 0 only. Indirect addressing, through page 0, must be used to address data between pages. Special instructions must be used to change Instruction Field or Data Field segments in LINC mode and to change memory fields in 8 mode.

Many of the peripheral devices available with the PDP-12 are controllable only in LINC mode. Of these, the A-D Converter and the CRT Display are used in the recognition program listed in Appendix A. The CRT Display, however, is not essential to the program and its use

will not be described in this report. The other peripheral devices used in the program, the Programmable Real-Time Clock and the Teletype device, may be controlled in either mode. A brief description of these devices and their use in the recognition program is given in the following paragraphs.

The A-D Converter consists of eight external input channels and eight internal input channels. The external input channels have an acceptable input voltage range of ± 1v, corresponding to a sample value range of $\pm 777_8$. The internal input channels (control knobs) also have a sample value range of $\pm 777_8$. One external input channel is used in the recognition program to sample the voltage level of the Morse code signal. Three internal input channels are used to set the input signal threshold level, the number of samples to be averaged, and the CHARACTER-WORD boundary adjustment value.

The Programmable Real-Time Clock consists of a 400 kHz crystal clock, a 12-bit counter register, and an overflow bit. The clock may be used to synchronize the central processor to external events, count external events, measure intervals of time between events, or provide program interrupts at intervals from 2.5 microseconds to over 40 seconds. The 400 kHz crystal clock may be used to provide pulses to the counter register at 100 Hz, 1 kHz, 10 kHz, 100 kHz, or 400 kHz rates; or an external source may be used to drive the counter. The clock is used in the recognition program to measure the time durations of pulses and spaces. An external source is used to permit variable counter rates in the 1 kHz to 10 kHz range.

The Teletype device is used to type in or print out information at a rate of up to ten characters per second. Similar devices, such as the

DECWRITER, operate at much faster rates. A DECWRITER was used during this project to print the test messages shown in Appendix D.

Certain distinguishing features of the two operating modes must be considered when changing modes within a program. One of these is the addressing scheme. In LINC mode, Instruction Fields and Data Fields consist of 1024-word segments. The addresses within each field range from 0000_8 to 1777_8, regardless of the physical location in core memory. Thus, location 0100_8 in Data Field 3 corresponds to physical location 6100_8 in core memory. In 8 mode, address locations correspond exactly to physical locations.

Another distinguishing feature between the two modes concerns arithmetic operations. LINC mode uses 1's complement addition for most operations, whereas 2's complement addition is used in 8 mode. As an example, 7777_8 is interpreted in LINC mode as -0 and in 8 mode as -1. Also, $7777_8 + 0001_8$ yields 0001_8 in LINC mode and 0000_8 in 8 mode.

Operational Goals. It goes without saying that the overall operational goal is accuracy. The output of the computer recognition program should exactly reproduce the hand-sent Morse code transmission. But by what measure should the accuracy of the program be evaluated? Should the program output be compared with that which a human would interpret as the transmitted message? Or should it be based strictly on the quality of the received code, as compared to the standards for Morse code language? Both evaluation criteria merit consideration. Further discussion of this topic is presented in Chapter VI.

Three operational goals are specified for the computer recognition program. These are:

1. The program must be able to process the received Morse code transmission in real-time.
2. The final program must occupy less than 4K of memory space.
3. The program should be designed to lend itself to construction of a small, low-cost hardware realization. i.e., a special purpose minicomputer.

These goals are somewhat interrelated. If the recognition program cannot process the received Morse code in real-time, a memory storage unit is required to save the received signal until it can be processed, thus requiring additional core space. In this case, the size of the memory will determine the maximum length message that could be processed at any one time. The real-time constraint eliminates this problem.

The 4K memory limitation was chosen to permit implementation of the program within one basic unit of memory. Thus, the recognition program can be implemented on the basic PDP-12 or similar minicomputer.

Construction of a hardware realization of the recognition program is of particular interest at the Air Force Institute of Technology. Aside from obvious educational benefits, construction of a low cost, portable Morse code recognition machine has many military and civilian applications. Proper choice of computer instructions, along with compliance to the aforementioned goals, will result in a minimum number of components necessary to construct a hardware realization.

Program Description

The recognition program is segmented into two major parts: the Signal Processing section (Fig. 4-1), and the Code Translation section

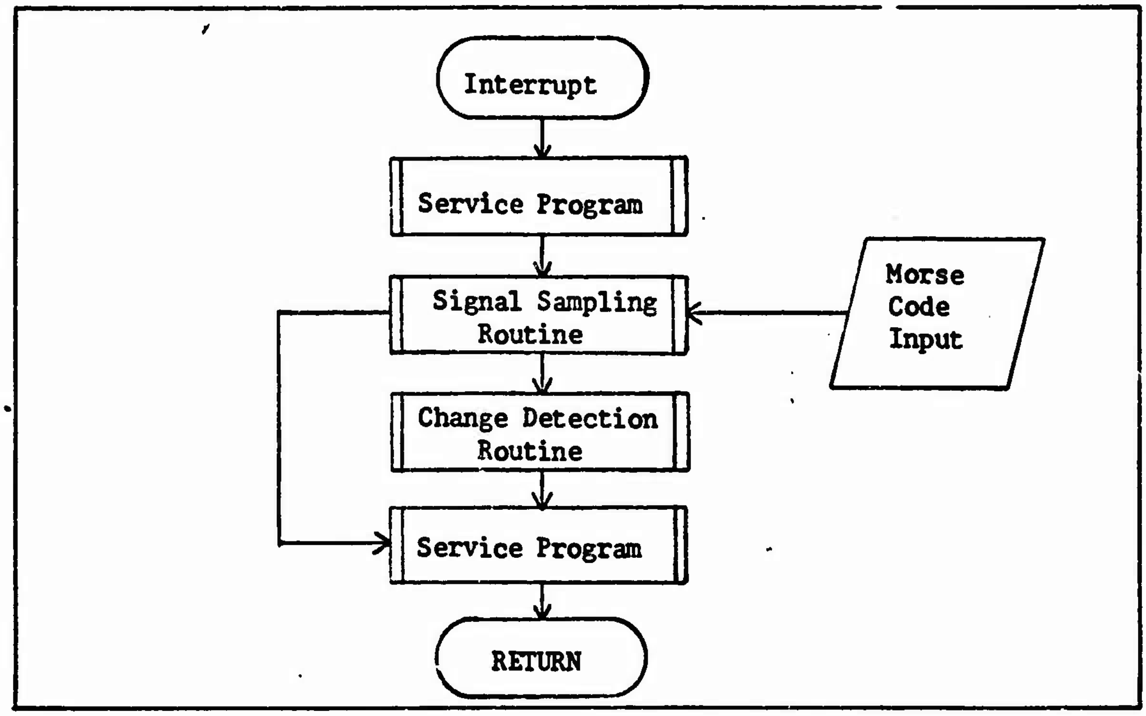


Fig. 4-1. Signal Processing Section Organization.

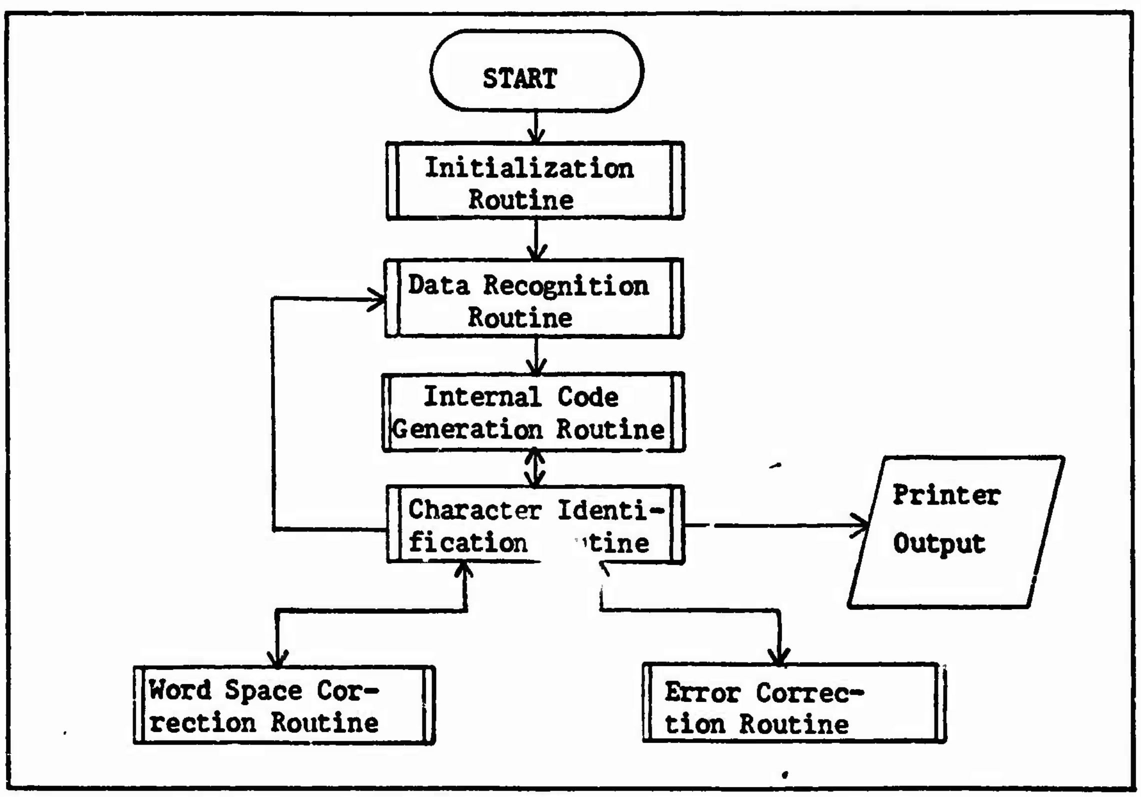


Fig. 4-2. Code Translation Section Organization.

(Fig. 4-2). The Signal Processing section serves to transform the received Morse code analog signal into pulse and space time duration information for use in the Code Translation section. The Code Translation section then uses these time durations to identify transmitted Morse code characters and print out the message. Detailed discussion of these two sections and their associated routines is presented in subsequent paragraphs.

Program operation in either section is controlled by an external program interrupt. Acknowledgement of a program interrupt is controlled by the status of an interrupt bus. If the bus is enabled, a program interrupt will halt current computer execution and transfer operation to absolute memory location 0001_8 in 8 mode or 0040_8 in LINC mode. If the interrupt bus is disabled, a program interrupt has no effect on execution. When a program interrupt is recognized and operation is transferred to the appropriate location, the interrupt bus is automatically disabled. The interrupt bus can only be enabled again by specific program instruction.

The interrupt bus is enabled during operation in the Code Translation section only. When an interrupt occurs, execution in that section is halted and the Service program (Fig. 4-3) is entered through location 0001_8 or 0040_8, depending on the computer mode at the time of interrupt. In either case, the current accumulator, link, and program counter register values are saved for use in returning to interrupted program. Signal Processing section operation then begins and continues until complete, at which time the Service program is reentered. Appropriate register values are restored, the interrupt bus is turned on, and operation again resumes in the Code Translation section at the point of interruption. Operation continues in this section until the occurrence of another inter-

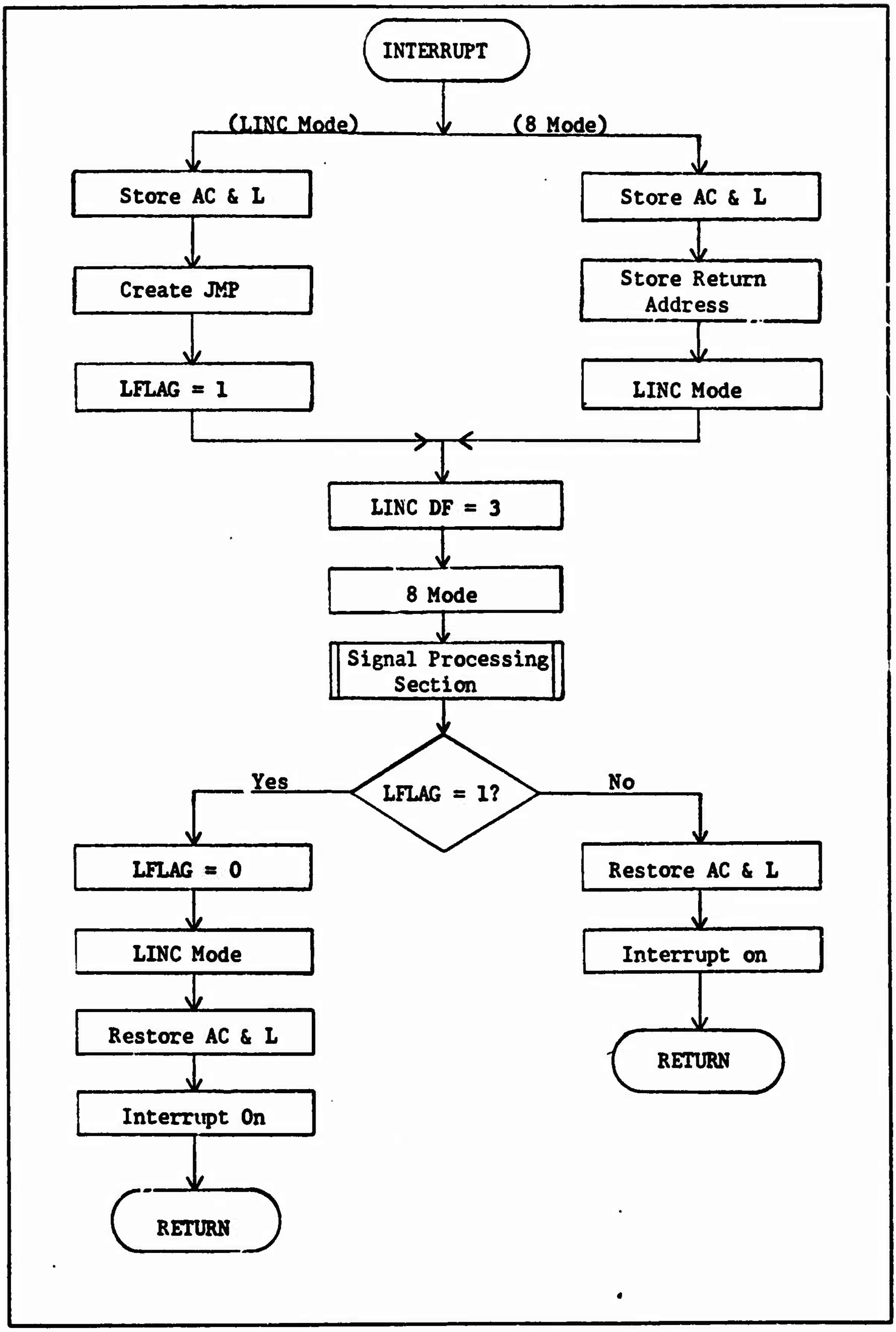


Fig. 4-3. Service Program Flowchart.

rupt, at which time the process is repeated.

Signal Processing Section

The Signal Processing section, as previously mentioned, serves to transform the received analog Morse code signal into pulse and space time duration information for use in the Code Translation section. If the received signal were completely clean and interference free, this transformation would be relatively easy. However, the transformation becomes rather difficult when the effects of noise and signal fading are considered. The main purpose, then, of the Signal Processing section is to recognize the Morse code transmission under realistic conditions of signal fading and distinguish it from pulse interference and "white" noise. The methods used to achieve these tasks will now be discussed.

The incoming pulse-modulated signal is first converted into dc pulses, corresponding to the Morse code being received, by a full-wave bridge rectifier and RC filter. The input signal voltage level is sampled periodically (approximately once every 200 microseconds) and compared to a threshold voltage level. If the input signal is less than the threshold level, a -1 is stored; if the input signal is greater than the threshold level, a +1 is stored. The effects of signal fading may be reduced by proper settings of the input signal voltage and threshold level.

A low pass digital filter technique is employed to limit the effects of noise on the input signal. Rather than base the pulse-space decision on whether the input signal level is above or below the threshold level for any one particular sample, the average of several of the samples must be above or below the threshold before a pulse-to-space or space-to-pulse

change is detected.

When an input signal level change is detected, it is checked again to determine if the change is permanent. The checking process is similar to the change detection process, except that twice as many samples are averaged. If the checking process result confirms the input signal change, then the signal is considered to have changed permanently. The time duration of the just-ended pulse or space is then obtained from the real-time clock counter and the clock is reset to begin timing the next pulse or space. If the result of the checking process conflicts with the change detection process, then the input signal change was due to interference rather than a valid Morse code input. In this case, the change detection process is repeated, again looking for an input signal level change.

When a valid input signal change is detected, the pulse or space time duration is stored in a 200_8-word memory buffer. Previously stored time durations are retrieved from the buffer as needed by the Code Translation section for processing. The 200_8-word buffer permits the Code Translation section to temporarily lag behind the Signal Processing section without loss of Morse code signal information.

This method of storage and retrieval of Morse code time durations presents an operational limit to the overall recognition program in that it is possible to over-write previously stored time durations before the Code Translation section processes them. If the interrupts occur too frequently, not enough time will be available for the Code Translation section to keep up with the storage of new time durations, a function of the Morse code transmission speed. Thus, the interrupt frequency upper limit is determined by the execution time of the Code Translation section. Fortunately, this presents no real problem to the overall recognition

program, since the upper limit is well above the minimum input signal sample frequency needed to ensure proper detection of Morse code signal changes.

The Signal Processing section is divided into two separate routines: 1) the Signal Sampling routine (Fig. 4-4), and 2) the Change Detection routine (Fig. 4-5). The particular function of these routines is discussed in the following paragraphs.

Signal Sampling Routine. The Signal Sampling routine performs the actual sampling of the Morse code input signal. If the sampled input voltage is greater than the threshold level, a +1 is stored. If the sampled input voltage is less than the threshold level, a -1 is stored. If N' samples have not been taken yet, program operation is returned to the Code Translation section through the Service program. When the N'th sample is taken, program operation continues in the Change Detection routine.

Change Detection Routine. The Change Detection routine performs the change detection and checking processes. After the N'th signal sample has been taken, the N' ±1s are added together to yield a positive or negative result. A +1 is assigned for a positive result and a -1 is assigned for a negative result. This value is then compared with the + or - 1 representing the current input signal level. If the comparison indicates that a change has occurred, the checking process is initiated to confirm or deny the change. If the comparison indicates that no change has occurred, program operation is returned to the Code Translation section through the Service program and the N' sampling process is started again.

As an example, assume that a Morse code pulse is being received.

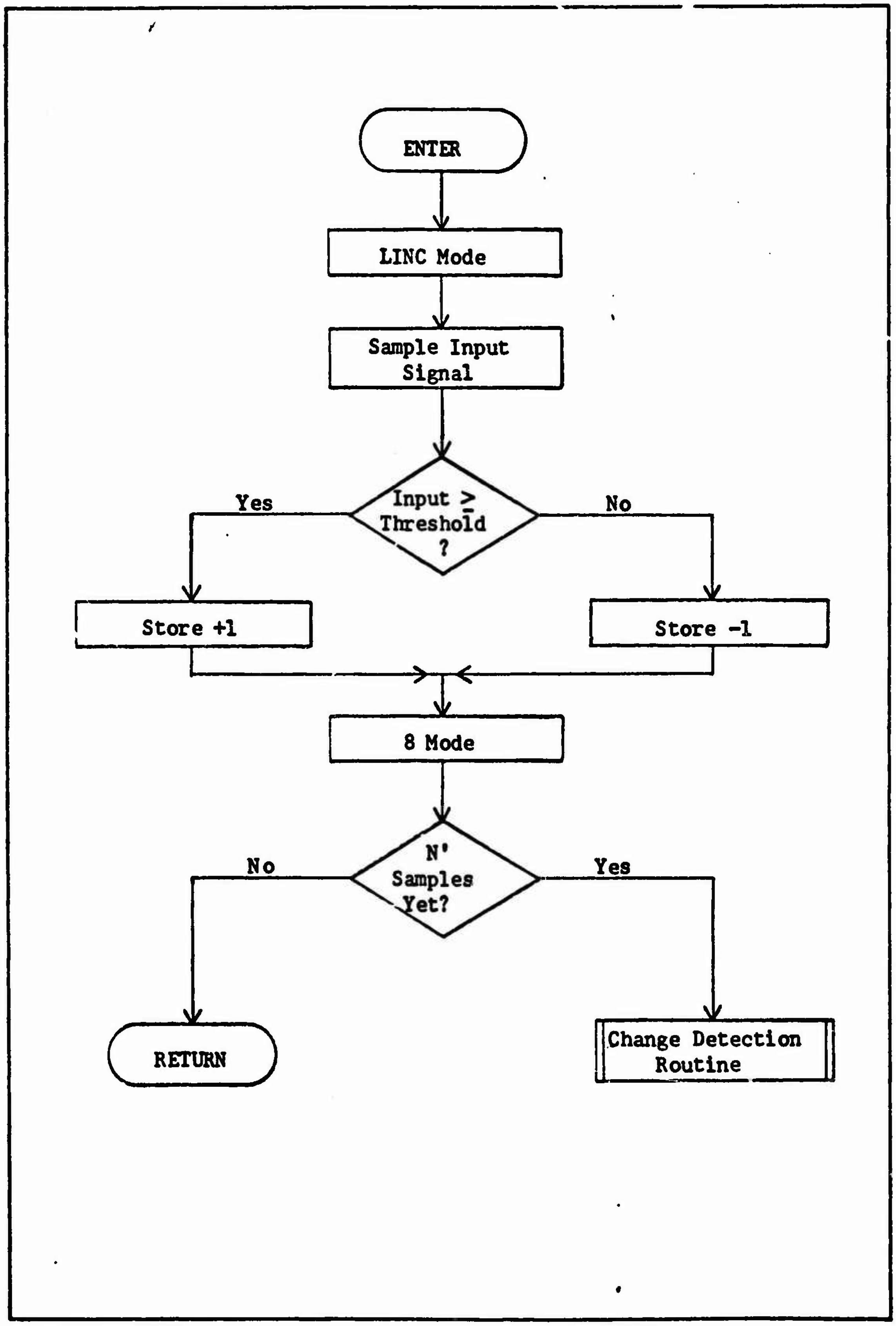


Fig. 4-4. Signal Sampling Routine Flowchart.

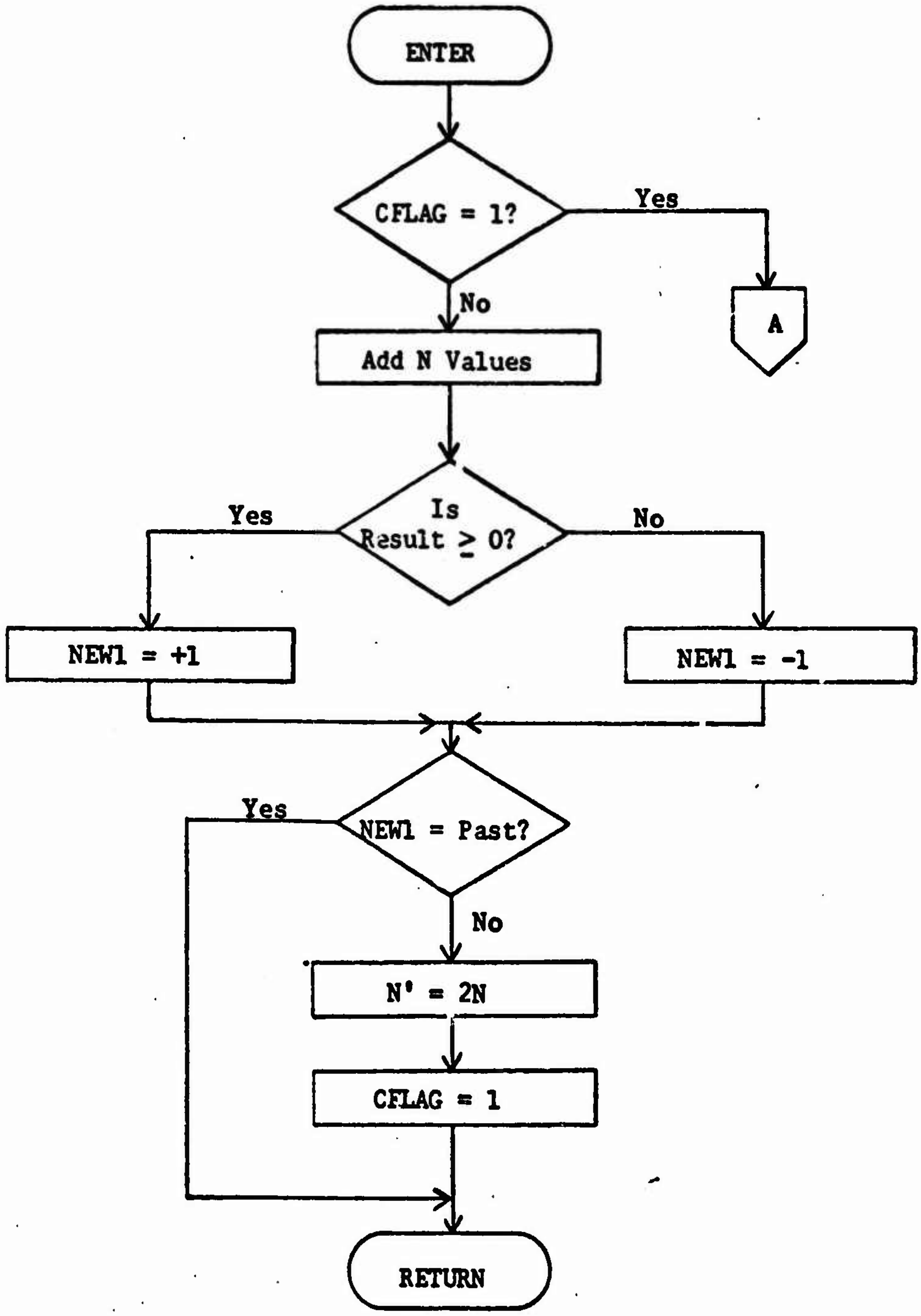


Fig. 4-5. Change Detection Routine Flowchart

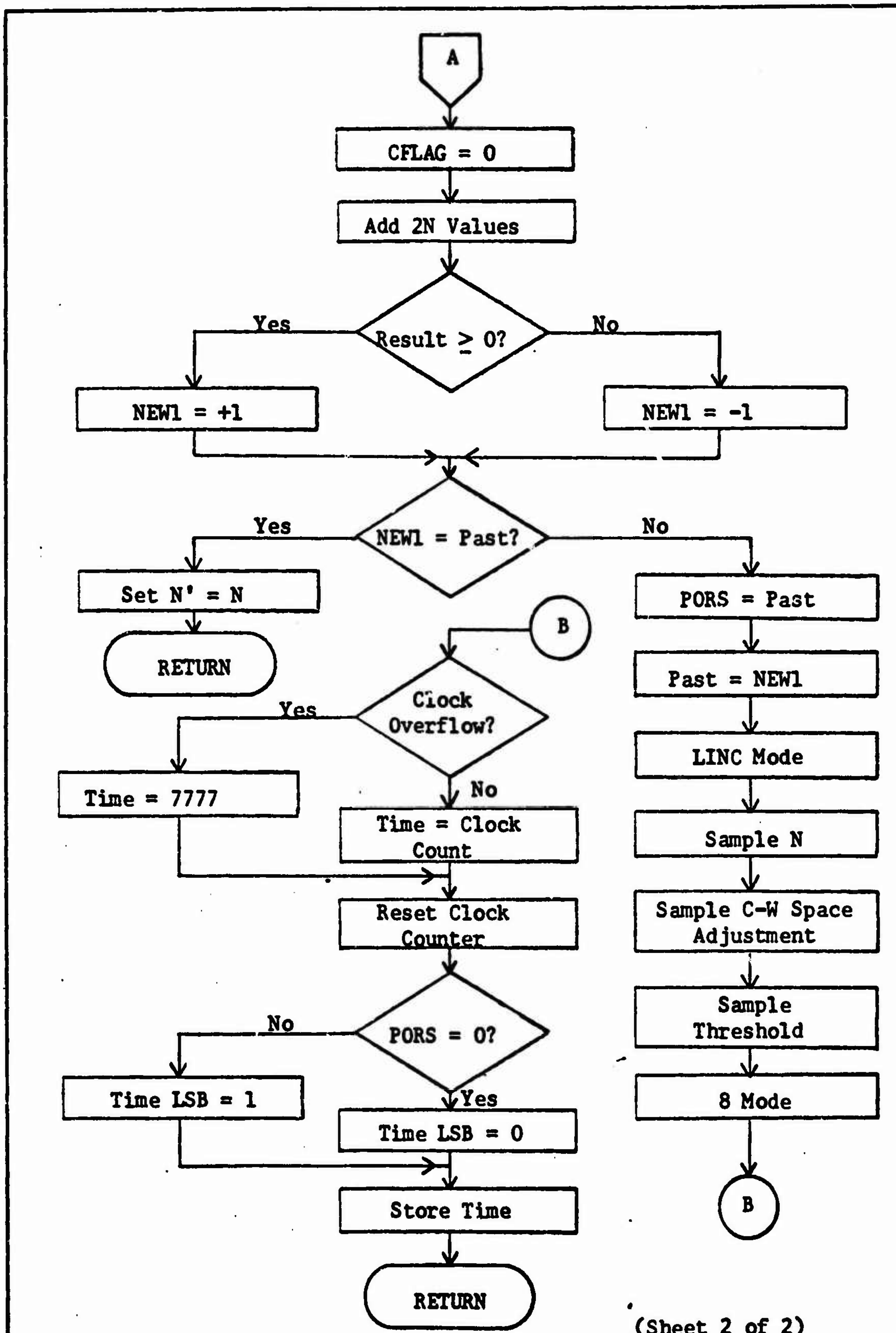


Fig. 4-5. Change Detection Routine Flowchart.

When the input signal changed from the previous space to the current pulse, the time duration of the space was recorded and stored, and a +1 was stored to indicate that a pulse is currently being received. After every N' samples are averaged, the ± 1 is compared with the stored +1 value. A change is indicated when the N' sample average is -1. The checking process then begins. If the result of the checking process also indicates a -1, then the input signal is considered to have permanently changed to the succeeding space and the time duration of the just completed pulse is read from the real-time clock and stored. This time duration is then marked as a pulse by setting the least significant bit (LSB) of the time duration to a 1. Likewise, the LSB is set to a 0 for a space. In this way, the Code Translation section can correctly identify pulses and spaces.

The real-time clock counter has a range of 0000_8 to 7777_8. If a space or a pulse is long enough, the counter will count past 7777_8 and restart at 0000_8. When this occurs, an overflow bit is set. Subsequent overflows will not reset the overflow bit. When a permanent change is detected the overflow bit is checked first before the clock counter is read. If an overflow has occurred, a clock value of 7777_8 is automatically assumed. The actual clock counter value is read only if an overflow has not occurred, thereby preventing erroneous time durations from being used in the program.

The actual time duration of a pulse or space is determined by the real-time clock frequency. This frequency is set to permit counter readings for the longest pulse or space to be below the overflow condition. Thus, overflows will normally only occur when there is a long pause between Morse code transmissions.

Code Translation Section

The Code Translation section converts the stored pulse and space time duration information produced by the Signal Processing section into a printed copy of the received Morse code message. This section is composed of six routines: 1) the Initialization routine, 2) the Data Recognition routine, 3) the Internal Code Generation routine, 4) the Character Identification routine, 5) the Word Space Correction routine, and 6) the Error Correction routine.

Recognition program operation begins in the Code Translation section. Pulses and spaces are identified by comparing the time duration of a particular pulse or space to the average of past pulses and spaces. Before any decisions can be made in this manner, some a priori knowledge of the particular averages must be obtained. The Initialization routine provides this knowledge by examining the first 49 pulses received, in a two-step process. The acquired knowledge is then used to start the recognition process, commencing with the first pulse or space received. As subsequent pulses and spaces are processed, the averaging information is constantly updated to adjust to changes in Morse code sending rates.

Pulses retrieved from the 200_8-word memory buffer are compared with the pulse average. If the time duration of the new pulse is greater than this average, it is classified as a DASH, otherwise it is a DOT. The receipt of a DASH is noted by storing a 1 in a word register. A 0 is stored in the word register to indicate the receipt of a DOT. The number of pulses received is recorded by incrementing a number register.

Spaces are classified in a two-step process. First, the time duration of the space in question is compared with the SYMBOL space boundary value. If the time duration is less than this boundary value, the new space is

classified as a SYMBOL space. If the time duration is greater than the boundary value, the new space is either a CHARACTER or a WORD space. The second step of the space classification process is then used to make this distinction. The time duration of the new space is compared with the CHARACTER-WORD space boundary value. If the time duration is less than this value, the new space is classified as a CHARACTER space; otherwise it is classified as a WORD space.

When either a CHARACTER space or a WORD space is identified, the contents of the word and number registers are combined to yield a unique internal code word representing the received Morse code character. This internal code word is then compared with a list of internal code words stored in memory. The corresponding ASCII Teletype code is identified and used to print the character. A list of internal code words is presented in Appendix C.

When the internal code word cannot be identified as a valid code word, an error correction process is initiated. This process, when possible, corrects two types of errors: 1) the inclusion of an extra pulse in the code word due to noise in the received Morse code signal, and 2) the joining of two Morse code characters caused by too small a space separating the characters. In the first case, pulses having a time duration less than one-half of the current DOT average are eliminated. The internal code word is then recomputed and the valid character is identified. If no pulses can be eliminated in this process, the second case is considered. The largest SYMBOL space in the invalid code word is reclassified as a CHARACTER space. Two new internal code words are generated from the invalid code word and reprocessed. If either of the corrected internal code words is still invalid, a special error symbol is

printed to indicate receipt of an unidentifiable Morse code character.

Recognition of a WORD space causes the Teletypewriter to skip a space, thereby forming words rather than an endless string of transmitted characters. However, the overlap of CHARACTER and WORD space time durations, as shown in Chapter III, causes some CHARACTER spaces to be erroneously classified as WORD spaces. In order to limit the number of erroneous classifications, a separate routine is used to re-evaluate WORD spaces following the letters I, J, Q, U, V, and Z. The occurrence of these letters as the last letter of an English language word is highly unlikely, although not impossible. This routine compares the time duration of the space in question with a slightly larger boundary value. If the time duration is greater than this new boundary value, the space is classified as a CHARACTER space. The readability of the printed message is greatly improved through the use of this technique.

Discussion of the particular functions performed by each of the six routines contained in the Code Translation section is now presented in the following paragraphs.

Initialization Routine. The Initialization routine (Fig. 4-6) is entered from the Data Recognition routine. Operation begins by enabling the interrupt bus. Then the first 49 pulses (98 stored pulse and space time durations) are examined to establish initial average information. This process is accomplished in two steps. First, the time durations of the first 16 pulses are averaged to establish approximate DOT, DASH, and pulse averages according to the following set of equations:

$$\text{DOT AVG.} = \frac{\text{DOT AVG.}}{2} + \frac{\text{NEW DOT}}{2} \qquad (4.1)$$

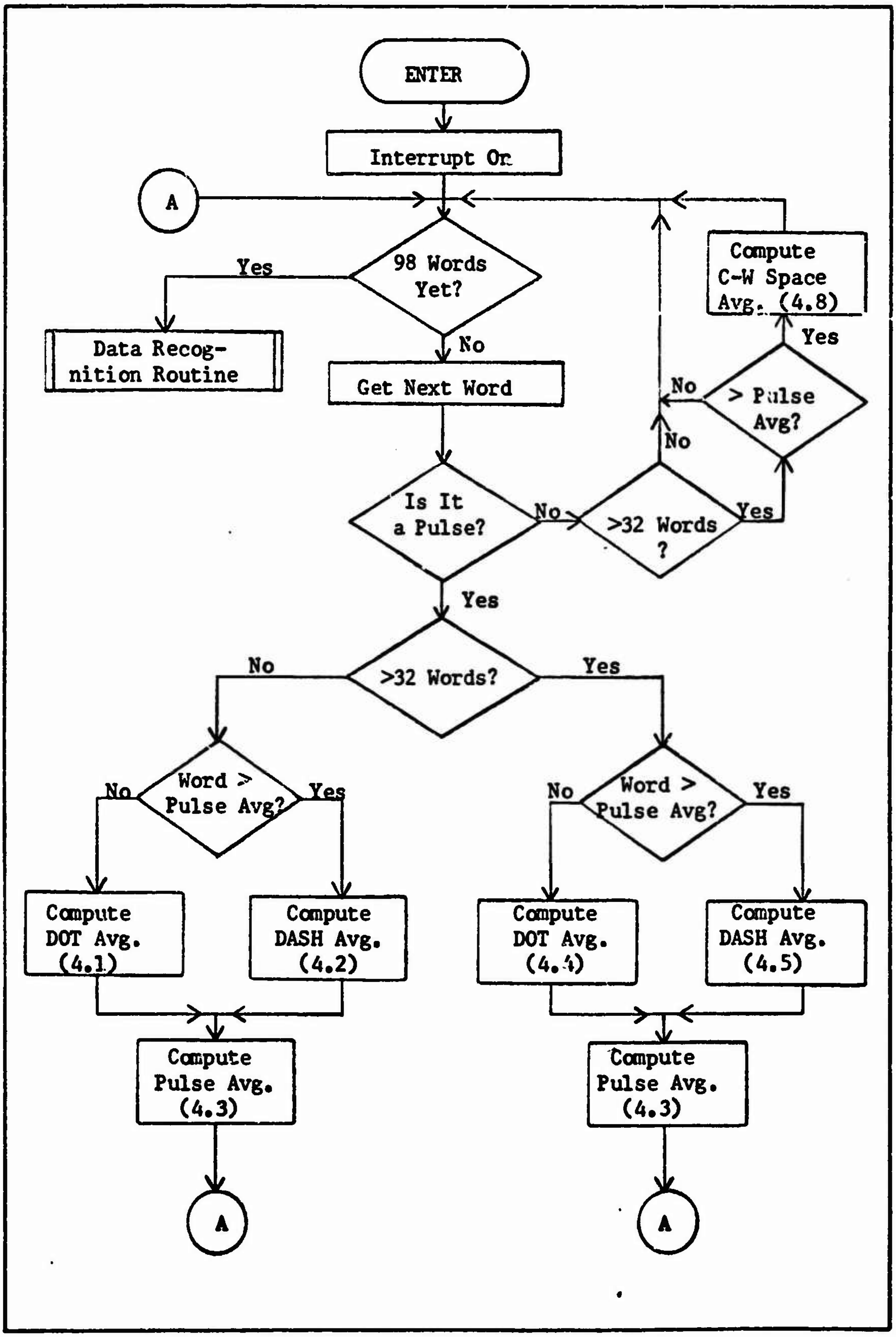


Fig. 4-6. Initialization Routine Flowchart.

$$\text{DASH AVG.} = \frac{\text{DASH AVG.}}{2} + \frac{\text{NEW DASH}}{2} \quad (4.2)$$

$$\text{PULSE AVG.} = \frac{\text{DOT AVG.}}{4} + \frac{\text{DASH AVG.}}{2} \quad (4.3)$$

All averages are initially set at 0. The first pulse is automatically classified as a DASH, regardless of its actual classification, because it is greater than the pulse average. The DASH and pulse averages are then computed according to the above equations. The second pulse is then compared with the pulse average and classified as a DOT or a DASH and the DOT average or DASH average is computed, as applicable. After three or four of each type of pulse has been processed, the resulting averages approach their true values. Note that the DOT and DASH averages are heavily influenced by the time duration of each new pulse. This permits the rapid establishment of initial averages; however, these averages are too sensitive to extreme deviations from the mean and are not desirable for long term use. Also note that the pulse average is not the mean of the DOT and DASH averages, but is, instead, shifted slightly towards the DOT average. As was shown in Chapter III, this slight compensation positions the pulse linear decision boundary in the center of the gap between DOT and DASH time duration clusters. Equation (4.3) is used throughout the recognition program to compute the pulse average.

In the second step of the Initialization routine, an improved set of DOT and DASH average equations, less sensitive to temporary time duration deviations from the mean, are used to refine the DOT, DASH and pulse averages:

$$\text{DOT AVG.} = \text{DOT AVG.} - \frac{\text{DOT AVG.}}{4} + \frac{\text{NEW DOT}}{4} \quad (4.4)$$

$$\text{DASH AVG.} = \text{DASH AVG.} - \frac{\text{DASH AVG.}}{4} + \frac{\text{NEW DASH}}{4} \quad (4.5)$$

The time durations of the remaining 33 pulses are averaged according to these equations. The pulse average, as always, is recomputed after each DOT or DASH average computation.

Upon completion of the initialization process, the DOT and DASH averaging equations are again changed to the following for use throughout the rest of the program:

$$\text{DOT AVG.} = \text{DOT AVG.} - \frac{\text{DOT AVG.}}{8} + \frac{\text{NEW DOT}}{8} \quad (4.6)$$

$$\text{DASH AVG.} = \text{DASH AVG.} - \frac{\text{DASH AVG.}}{8} + \frac{\text{NEW DASH}}{8} \quad (4.7)$$

The initial CHARACTER-WORD space average is also established during the Initialization routine. After the first 16 pulses have been examined and the preliminary pulse averages determined, the space averaging process begins. The space time duration is first compared with the pulse average to determine whether it is a SYMBOL space or not. If it is not, the CHARACTER-WORD space average is computed according to the following equation:

$$\text{C-W SPACE AVG.} = \text{C-W SPACE AVG.} - \frac{\text{C-W SPACE AVG.}}{4} + \frac{\text{NEW SPACE}}{4} \quad (4.8)$$

Upon completion of the initialization process, the CHARACTER-WORD

space average computation is performed only for non-SYMBOL spaces preceeded by a DOT according to the following equation:

$$\text{C-W SPACE AVG.} = \text{C-W SPACE AVG.} - \frac{\text{C-W SPACE AVG.}}{8} + \frac{\text{NEW SPACE}}{8} \quad (4.9)$$

These final averaging equations allow the program to adjust to gradual changes without overly reacting to temporary fluctuations in pulse and space durations.

Data Recognition Routine. The Data Recognition routine (Fig. 4-7) begins after the initializing is complete. The first word is taken from the 200_8-word storage loop and identified as a pulse or space. If it is a pulse, it is compared to the pulse average and identified as a DOT or DASH by the following equation:

$$X = \frac{\text{PULSE AVG.}}{2} - \frac{\text{NEW PULSE}}{2} \quad (4.10)$$

$$(X \geq 0 \Longrightarrow \text{DOT}; X < 0 \Longrightarrow \text{DASH})$$

The respective averages are then recomputed to include the new input. A 0 or a 1 is stored in the word register to indicate receipt of the DOT or DASH, respectively, and the number register is incremented to keep track of the number of pulses received. The time duration of the pulse or space is successively stored in a 30_8-word memory location for use by the Error Correction process.

When a space is received, it is first catagorized by whether or not

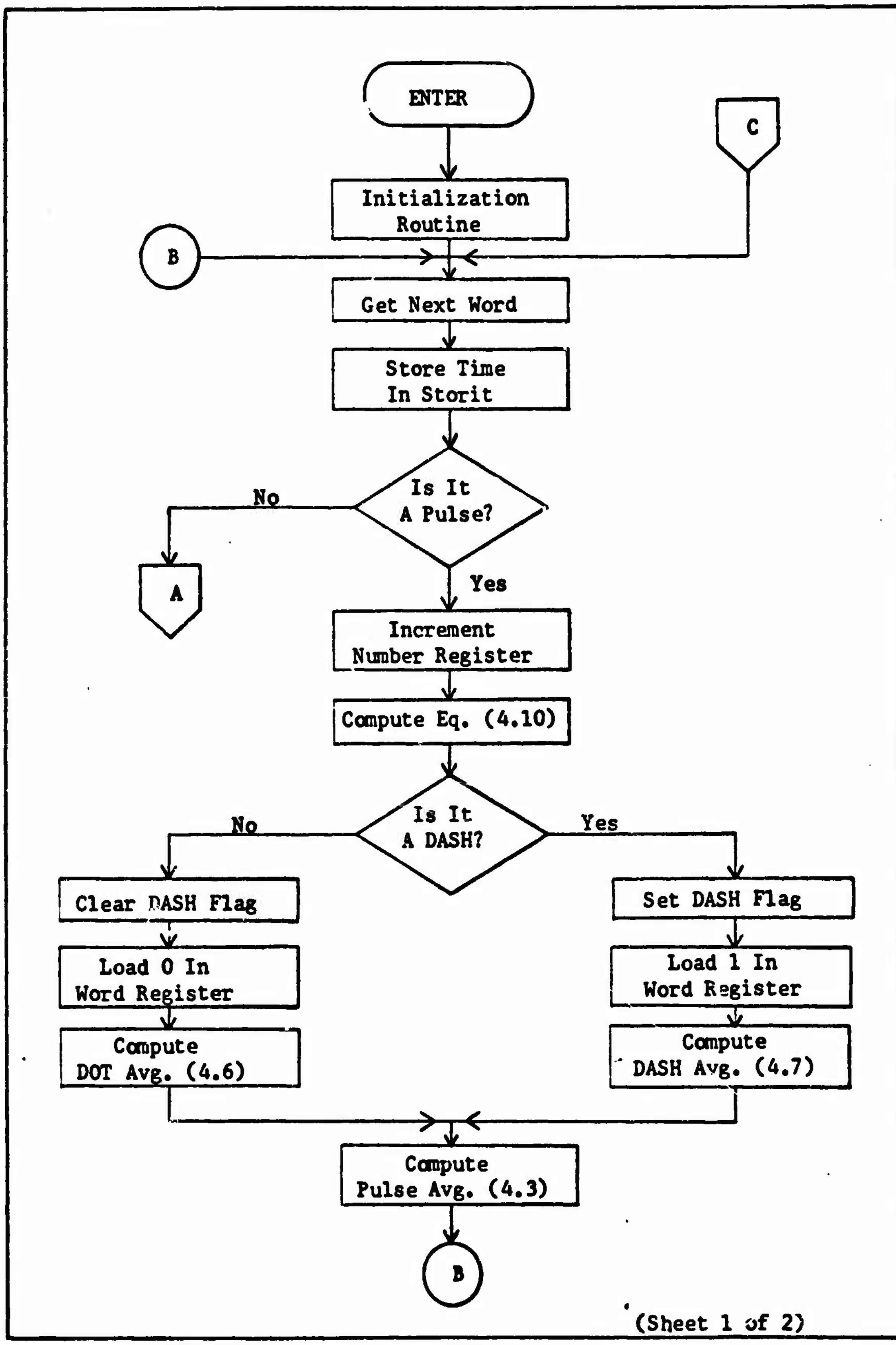


Fig. 4-7. Data Recognition Routine Flowchart.

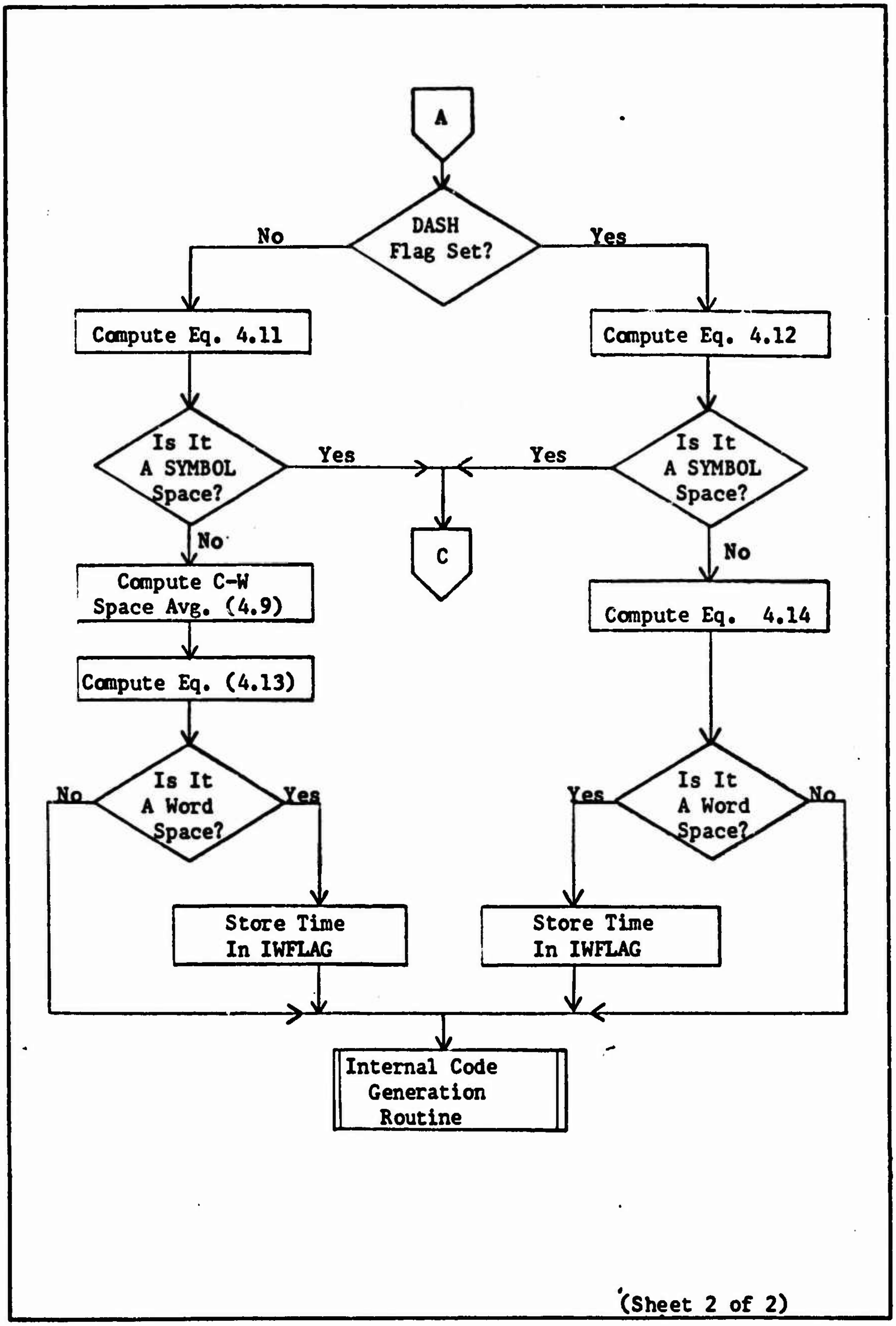


Fig. 4-7. Data Recognition Routine Flowchart.

it follows a DASH. This distinction is necessary to permit use of the proper decision algorithms as specified in Chapter III. The next step is to determine if it is a SYMBOL space or not. When the space follows a DOT, the following equation applies:

$$X = \frac{\text{NEW SPACE}}{2} - \frac{\text{PULSE AVG.}}{2} \tag{4.11}$$

$$(X < 0 \Longrightarrow \text{SYMBOL SPACE})$$

When the space follows a DASH, the equation is:

$$X = \text{NEW SPACE} - \frac{\text{PULSE AVG.} - \left[\frac{\text{DASH} - \text{PULSE AVG.}}{4}\right]}{2} \tag{4.12}$$

$$(X < 0 \Longrightarrow \text{SYMBOL SPACE})$$

If the space is identified as a SYMBOL space, the Data Recognition routine is repeated by examining the next word. If the space is not a SYMBOL space, then it must be identified as either a CHARACTER space or a WORD space. Again, this decision depends on the type of preceding pulse.

When the space follows a DOT, the following equation is used:

$$X = \frac{\text{NEW SPACE}}{2} - \frac{\text{C-W SPACE AVG.}}{2} \tag{4.13}$$

$$(X < 0 \Longrightarrow \text{CHARACTER SPACE};\ X \geq 0 \Longrightarrow \text{WORD SPACE})$$

When the space follows a DASH, the equation is:

$$X = \frac{\text{NEW SPACE}}{2} - \frac{\text{C-W SPACE AVG.} - \left[\frac{\text{DASH} - \text{PULSE AVG.}}{4}\right]}{2} \qquad (4.14)$$

$$(X < 0 \Longrightarrow \text{CHARACTER SPACE; } X \geq 0 \Longrightarrow \text{WORD SPACE})$$

When the space is identified as a WORD space, the time duration is stored in a special register (IWFLAG) for use by the WORD Space Correction routine. Normally, the identification of a WORD space causes the Teletypewriter to skip a space following the printed character.

Internal Code Generation Routine. The identification of either a CHARACTER space or a WORD space signals the end of a Morse code character. The Internal Code Generation routine (Fig. 4-8) then forms the internal code word by combining the contents of the word register with the number register to yield a unique 12-bit code word (See Appendix C for a listing of internal code words).

An example of this process is shown in Fig. 4-9. A "P" (DOT-DASH-DASH-DOT) is received and correctly identified by the Data Recognition Process. As each pulse is received, a 0 or a 1 is stored in the least significant bit of the word register and the number register is incremented by 1. Previously received 0's or 1's stored in the word register are shifted left one position to allow room for the new pulse. When a CHARACTER or WORD space is received, the content of the word register is shifted left 12-N positions (N = number register value), the content of the number register is added, and the result is stored in the code register.

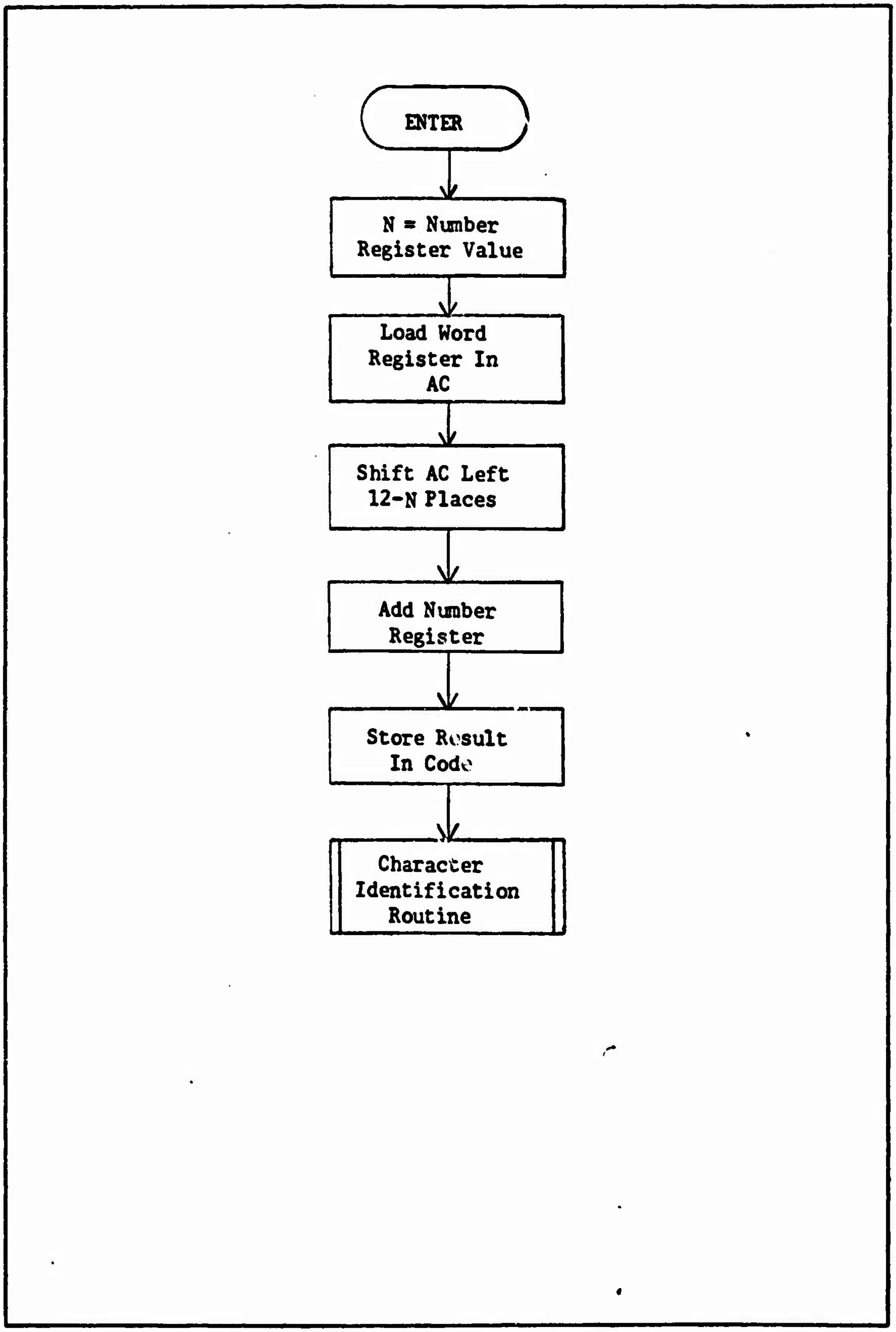


Fig. 4-8. Internal Code Generation Routine Flowchart.

Morse Code Character "P" (• — — •)
0 0 0 0 0 0 0 0 0 1 1 0
Word Register
0 0 0 0 0 0 0 0 0 1 0 0
Number Register
0 1 1 0 0 0 0 0 0 1 0 0
Internal Code Register (3004_8)

Fig. 4-9. Internal Code Word Generation

Because of the 12-bit register limitation on the PDP-12 computer, this internal process can only recognize Morse Code characters having eight or less pulses. Since most Morse code characters are 6 or less pulses long (error character has 8 pulses), this process is sufficient to handle the Morse code character set. The 12-bit register presents a limitation, however, to the Error Correction process, as discussed later in this chapter.

Character Identification Routine. The Character Identification routine (Fig. 4-10) compares the internal code word with a stored alphabet of 49 internal codes and selects the correct ASCII code for printer output. The comparison process has been divided into four steps to reduce computer execution time.

The first step determines which 4000_8 code subgroup ($0000_8 \longrightarrow 3777_8$ or $4000_8 \longrightarrow 7777_8$) the internal code word falls in. The second step identifies the 1000_8 subgroup containing the internal code. The third step identifies which half of the 1000_8 subgroup the code word is in.

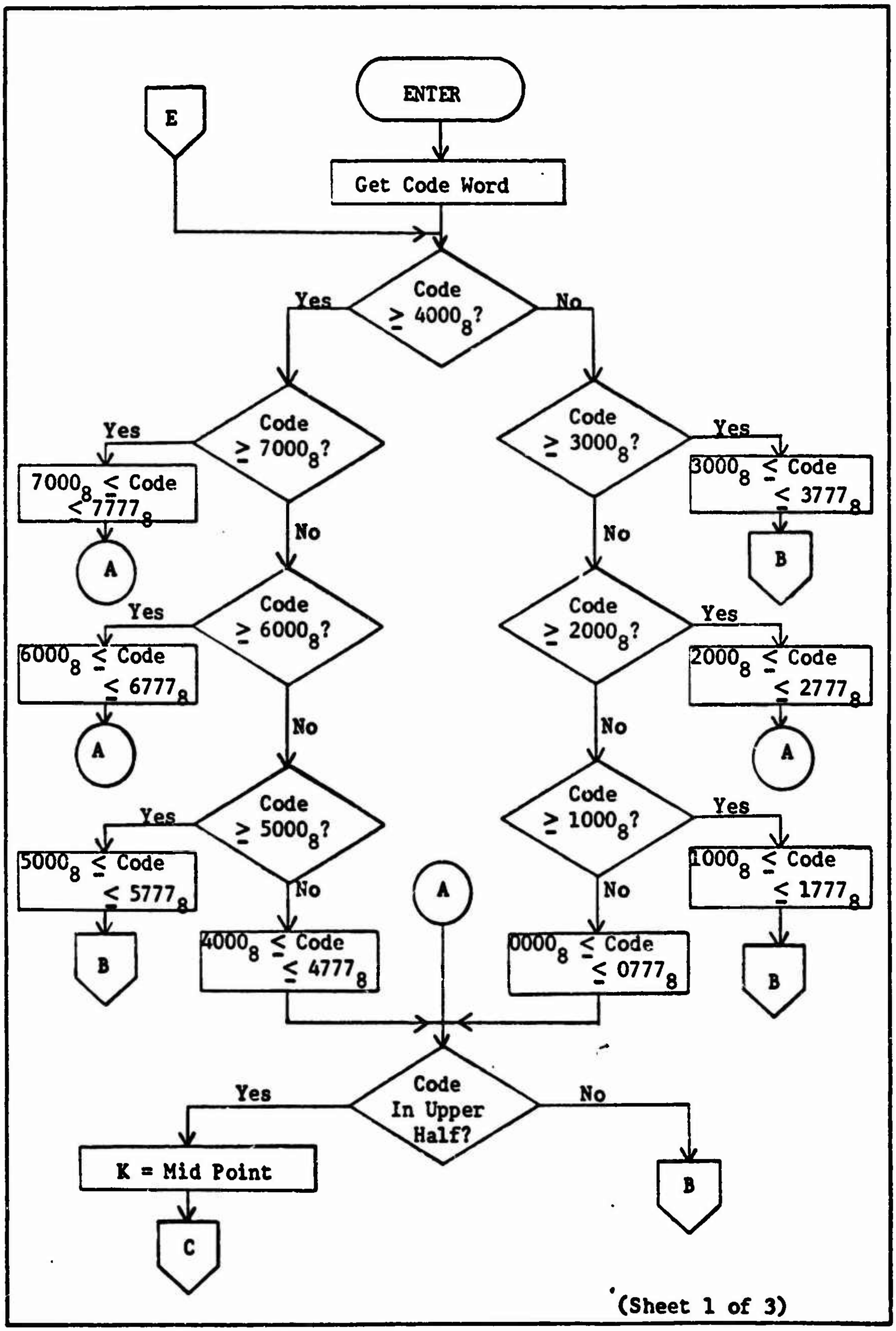


Fig. 4-10. Character Identification Routine Flowchart.

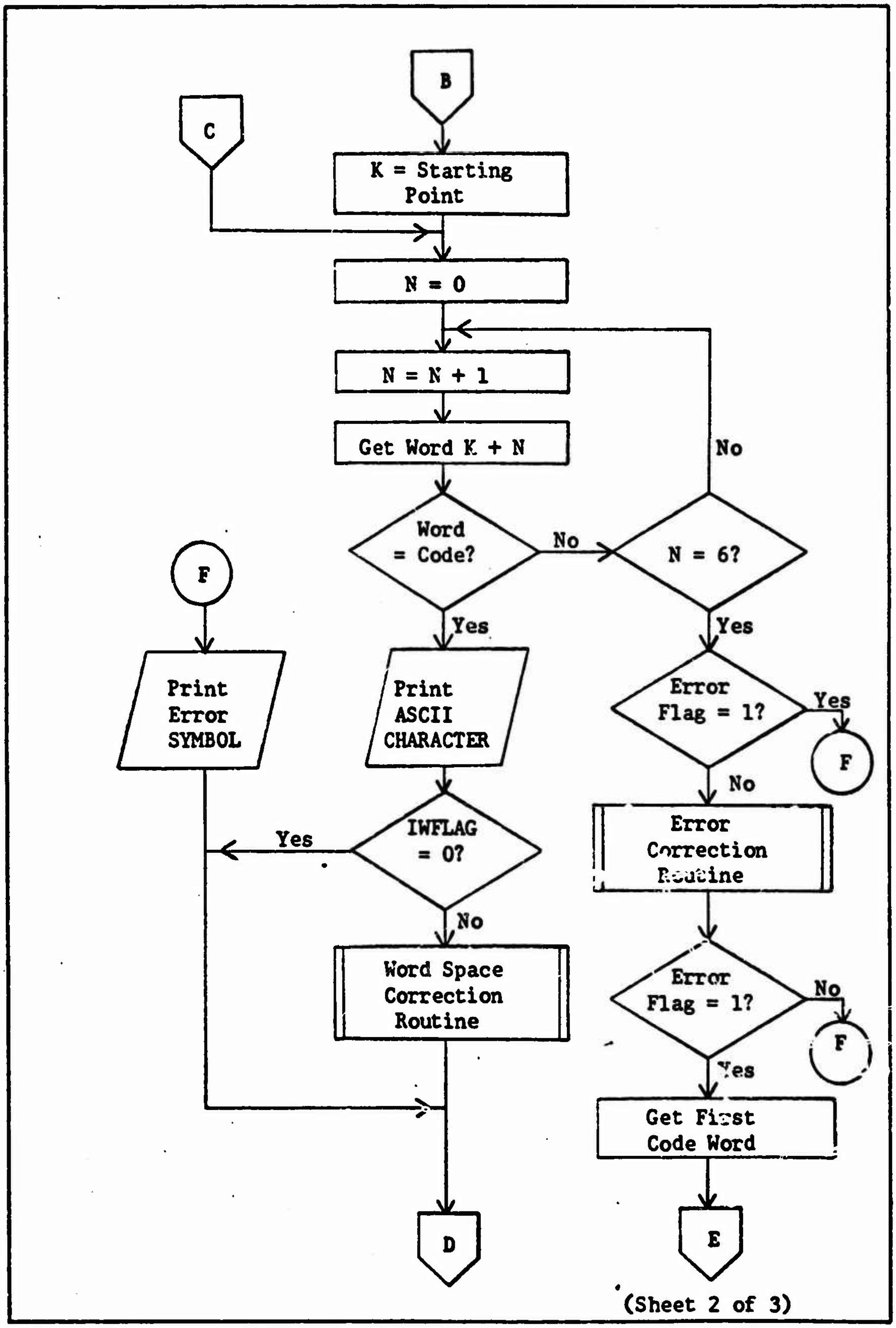
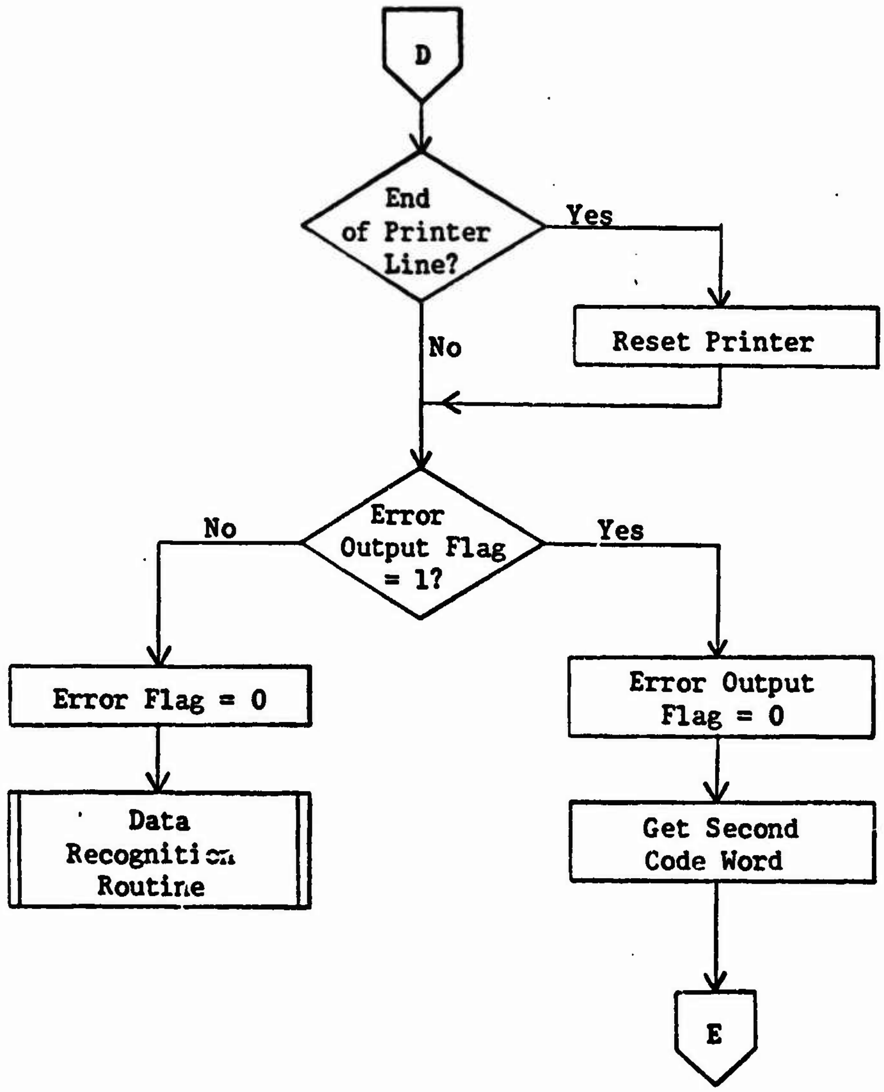


Fig. 4-10. Character Identification Routine Flowchart.



(Sheet 3 of 3)

Fig. 4-10. Character Identification Routine Flowchart.

Step 3 is only used for those subgroups having five or more code words. Finally, the fourth step identifies the correct internal code and corresponding ASCII code.

The identified ASCII character is then printed on the Teletypewriter. If a WORD space is identified, a blank is also printed. The printer carriage is controlled to provide double-spaced, 60-character lines.

If an internal code word cannot be identified, the Error Correction routine is entered. However, if the invalid code word is one which has been produced by the Error Correction routine, an error symbol is printed. Since it is possible for the Error Correction routine to generate two "corrected" code words, a network of flag checks is used to process each code word separately.

WORD Space Correction Routine. For the case of English language clear text transmissions, the occurrence of certain letters of the alphabet as the last character of a word is highly improbable, but not impossible. Six such letters are I, J, Q, U, V, and Z. When any of these characters is identified as the last character of a word, (i.e., followed by a WORD space), the WORD Space Correction Process is entered (Fig. 4-11). In this process, the word space is compared to a larger CHARACTER-WORD Space average than previously used. The adjusted average is the sum of the current CHARACTER-WORD Space average and the Pulse average, as shown below:

$$X = \frac{\text{C-W SPACE AVG.} + \text{PULSE AVG.}}{2} - \frac{\text{WORD SPACE}}{2} \tag{4.15}$$

$$(X < 0 \Longrightarrow \text{WORD SPACE};\ X \geq 0 \Longrightarrow \text{CHARACTER SPACE})$$

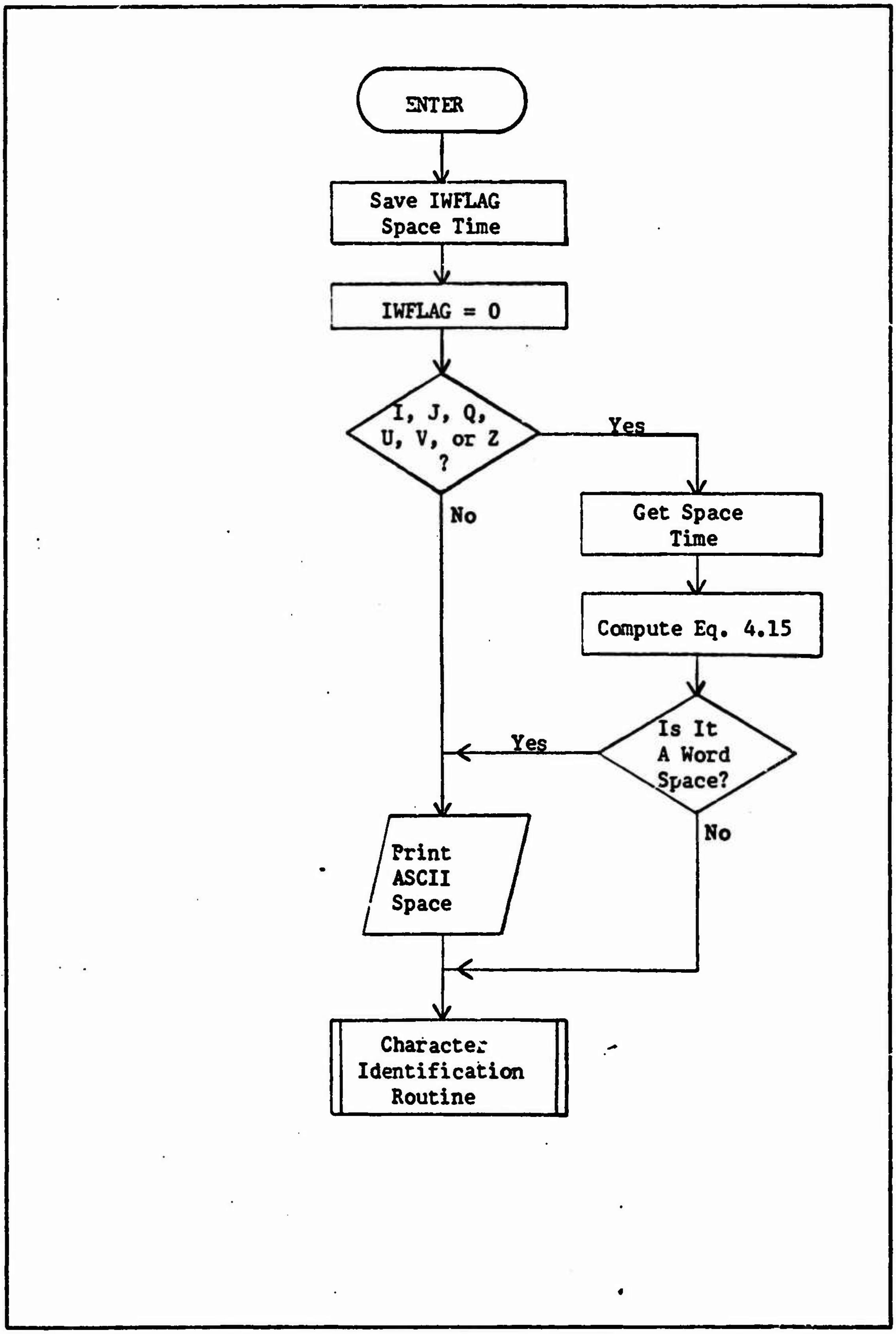


Fig. 4-11. Word Space Correction Routine Flowchart.

This calcualtion is used regardless of the type of preceding pulse.

If the space duration is greater than this adjusted average, it is still considered a WORD space. If, on the other hand, the space is less than the adjusted average, it is reclassified as a CHARACTER space instead of a WORD space.

The WORD Space Correction routine is applicable to English language clear-text transmissions only. If coded transmissions are received, this process may prove to be more of a hindrance than a help. The process is designed to correct mistakes on the part of the human sender, thus improving the readability of the recognition program output.

Error Correction Routine. The Error Correction routine (Fig. 4-12) is designed to correct errors due to either operator mistakes or signal noise. The Error Correction routine is entered only if the internal code word resulting from either of these two errors is unrecognizable by the Character Identification routine.

The Error Correction routine contains three successive parts, ordered by their relative importance to the process. In the first part, the number register is examined to determine if the maximum capability of 8 pulses has been exceeded in the invalid code word. If it has been exceeded, the Error Correction routine is exited and an error symbol is printed. If the limit has not been exceeded, the process advances to part 2.

The second part of the Error Correction routine is designed to eliminate extremely small DOT's caused by noise in the received Morse code signal. The pulses stored by the Data Recognition process are compared to a rejection value equal to one-half of the DOT average. The actual computation is:

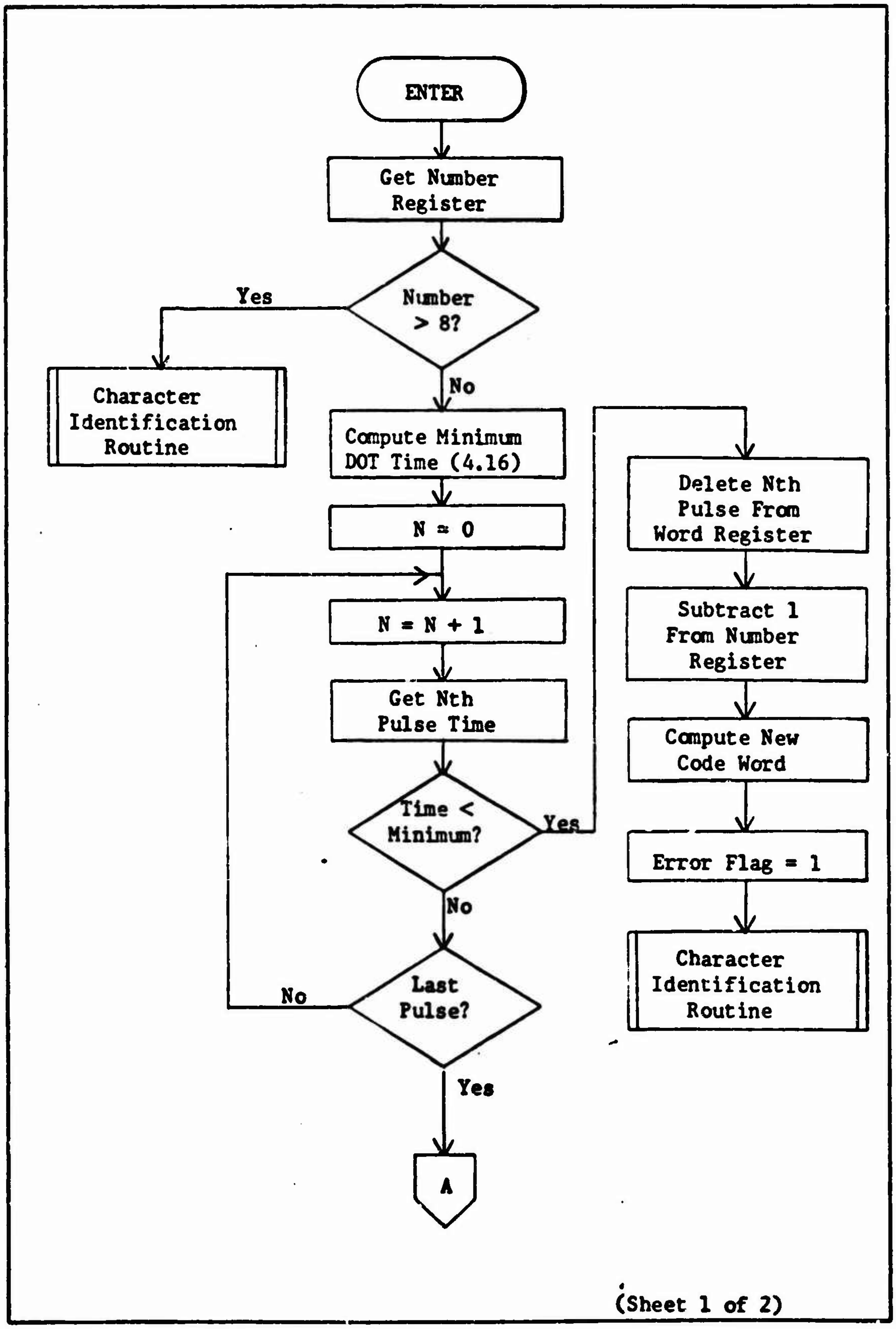


Fig. 4-12. Error Correction Routine Flowchart.

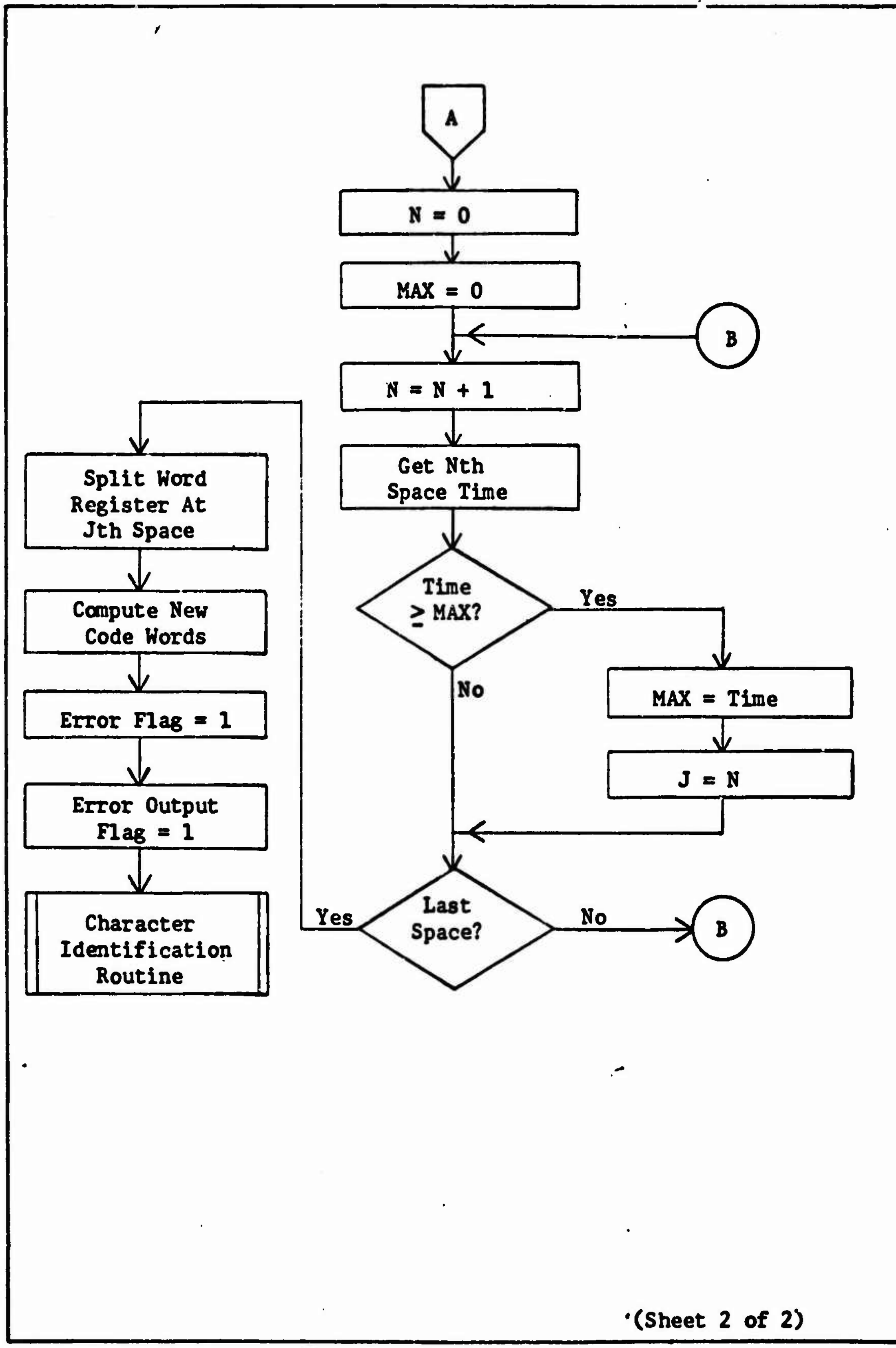


Fig. 4-12. Error Correction Routine Flowchart.

$$\text{MINIMUM DOT TIME} = \frac{\text{DOT AVG.}}{2} \tag{4.16}$$

If none of the pulses have a time duration less than the minimum value, the process advances to part 3. If, however, one of the pulses is less than the minimum value, a new internal code is generated by eliminating the erroneous DOT. The corrected code is then processed by the Character Identification routine.

The third and final part of the Error Correction routine is designed to separate two run-on characters caused by a short CHARACTER space. This program operates on the assumptions that the invalid character is composed of two and only two run-on characters, and that the intended CHARACTER space is the longest of the SYMBOL spaces contained in the invalid character. Spaces stored by the Data Recognition process are examined to determine the largest space within the invalid character. Two new internal codes are then formed by separating the invalid character at that point. These codes are then processed one at a time by the Character Identification routine. In addition, if the space following the invalid character was identified as a WORD space, a blank is printed following the second new character, unless prohibited by the WORD Space Correction routine.

New code words generated by either part 2 or part 3 may not be identifiable by the Character Identification routine. Since the stored time durations for the original invalid character no longer apply to the new code words, entrance into the Error Correction routine caused by invalid new codes must be prohibited. This is done by setting appropriate flags for use in the Character Identification routine.

V. Operational Procedure

This chapter describes the operational procedure used to initialize, run, and reset the recognition program listed in Appendix A. This procedure applies specifically to the particular PDP-12 computer and associated peripheral devices used in this project, as shown in Fig. 5-1; however, the procedure will apply, in general, to other possible configurations utilizing the techniques presented in this report.

System Initialization

After the recognition program is loaded into the PDP-12 computer, several steps must be performed to initialize the system, as follows: (Note: These steps can be accomplished in any order. Refer to Fig. 5-1 for equipment interconnections and control locations.)

1. Set the external Real-Time clock frequency. A value of 6000 Hz is best for hand-sent Morse code transmitted between 10 and 40 words per minute. Slightly higher or lower frequencies may be necessary for faster or slower transmission speeds, respectively.

2. Set the external program interrupt frequency. A value of 5000-6000 Hz is suggested; however, 6000 Hz is the maximum frequency that will allow proper operation of the Code Translation section. Higher program interrupt frequencies do not allow enough computer execution time for the Code Translation section to keep up with the output of the Signal Processing section.

3. Set the input signal threshold level. This value, set by rotating an A-D internal input channel control knob, has a range of $\pm 777_8$. A value of $+777_8$ is suggested; however, any value above 400_8 will suffice. The threshold level is displayed on the CRT Display screen during the initialization process as a horizontal line. A setting of $+400_8$ corresponds to the line being positioned in the center of the screen; $+777_8$ corresponds to the top

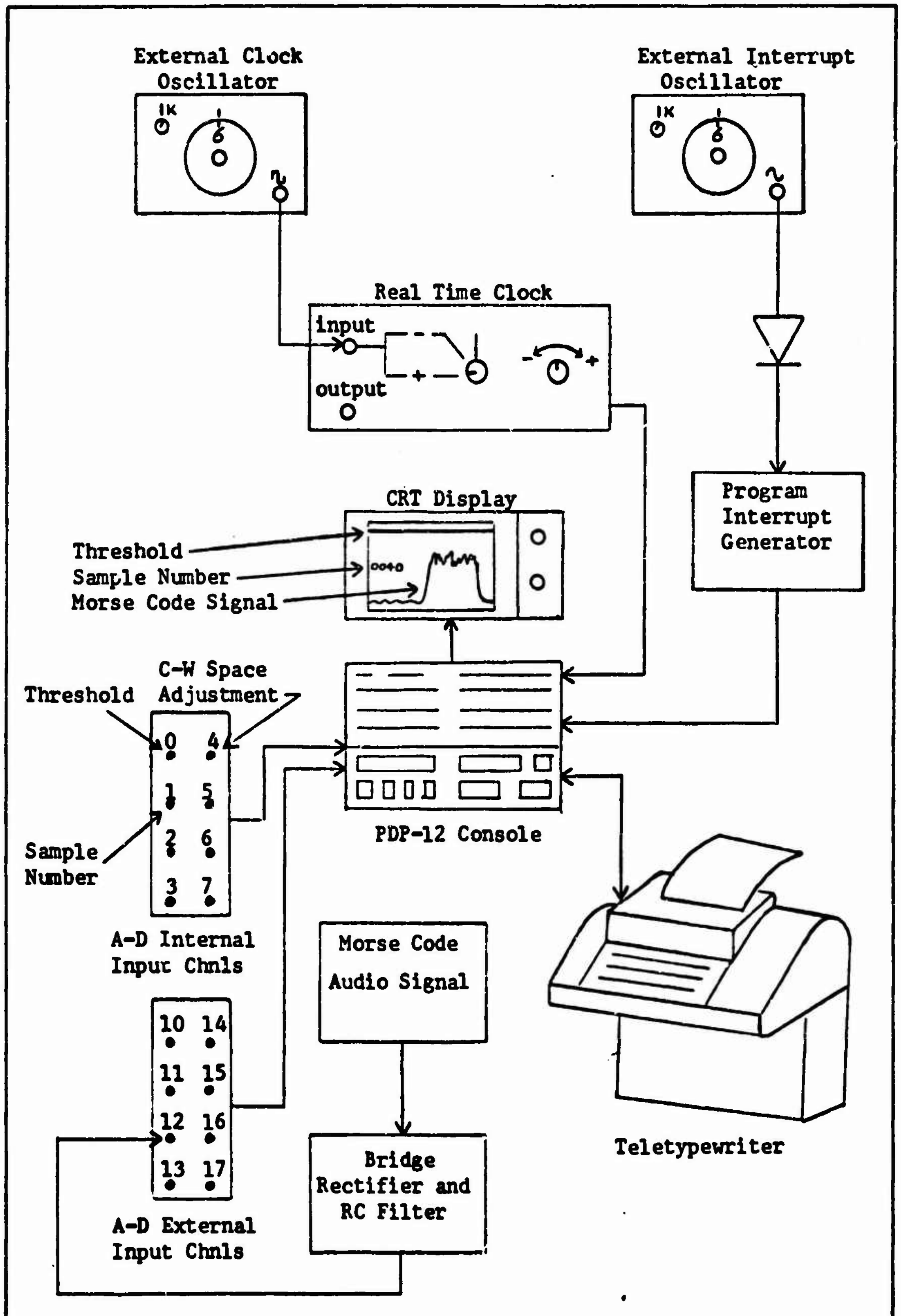


Fig. 5-1. Recognition Program Operational Configuration.

of the screen.

4. Set the peak rectified input signal voltage to approximately 2 volts. This signal is also displayed on the screen during the initialization process, provided a signal is being transmitted. The signal appears as a series of pulses flashing on the screen. As the input voltage level is increased, the peak of these pulses gets higher. The 2 volt level is reached when the pulse peaks disappear from view.

5. Set the number of input signal samples to be averaged. This number appears in the center left-hand side of the CRT Display screen during the initialization process. The number is set by rotating an A-D internal input channel control knob. An initial value of 0040_8 is recommended.

6. Set the CHARACTER-WORD space adjustment value to 0000_8. This value is also set by an A-D internal input channel control knob. These control knobs have a 10-turn stop-to-stop movement. 0000_8 corresponds to the center of the knob movement.

When these six steps have been completed, the Recognition program is ready to process Morse code transmissions. Since the CRT Display only functions during the initialization process, the internal input channel control knobs should be calibrated for use during Recognition program operation. Recognition program operation is started by depressing any one of the Teletype keys.

Real Time Adjustments

The settings established in the initialization process will, in most instances, provide satisfactory recognition program output. Under unusual circumstances, however, certain readjustments may improve overall performance and readability of the printed program output. A list of possible programs and suggested readjustments is presented in Table III.

The presence of an extreme amount of interference on the Morse code

input signal will adversely affect recognition program performance. Such noise, generally having a time duration near that of a DOT or longer, causes the DOT, DASH, and pulse averages to be offset, resulting in an erroneous output. The respective averages will, however, be restored to normal when the interference subsides.

TABLE III

Recognition Program Real-Time Adjustments

Problem	Solution
1. Too many split words.	1. Increase the CHARACTER-WORD Space adjustment setting.
2. Too many run-on words.	2. Decrease the CHARACTER-WORD Space adjustment setting.
3. Too many error symbol printouts (a) Clear Morse Code Signal (b) Noisy Morse Code Signal	3. (a) Increase or decrease the Sample Number setting to obtain the best output. (b) Lower the peak input signal voltage slightly and readjust Sample Number setting.
4. Long succession of E's or I's.	4. Most likely due to extremely noisy Morse Code signal. Increase Sample Number setting and perform restart procedure.

Restart Procedure

The restart feature provides the capability to return to the System Initialization point at the beginning of the recognition program. This is done by depressing and resetting (rocking) Sense Switch 1 on the PDP-12 console at any time during program operation. Program operation may be resumed again by depressing any one of the Teletype keys.

The restart feature provides two important capabilities to the program. First, it erases current average information. This is most

useful in the case where the averages are offset due to extreme signal interference. By performing a quick restart procedure (i.e., rocking Sense Switch 1 followed immediately by depressing a Teletype key), the erroneous averages are erased and new averages are established. Morse code information is lost only during the brief interval between the two actions.

Second, the restart procedure permits the last character of a Morse code transmission to be printed out. Normally, a Morse code character is not identified until either a CHARACTER space or WORD space is recognized. These spaces are recognized, as are all pulses and spaces, by their relative time durations. Space time durations are obtained when the succeeding pulse begins. If the pulse never occurs, as is the case at the end of a transmission, the last space time is never obtained and, as a result, the last Morse code character is not processed. Depression of the restart switch (Sense Switch 1) causes all unprocessed words stored in the 200_8-word memory buffer to be processed, including the last Morse code character received.

VI. Results

This chapter presents an evaluation of recognition program performance. Various types of Morse code transmissions were used to test the program. These include hand-sent Morse code transmitted via a simple hand key, a bug, and an electronic keyer, as well as machine-sent Morse code (Kleinschmidt-paper tape). The effects of noise on the performance of the recognition program was also tested.

The types of errors made by the program were mainly due to characteristics peculiar to the sender. A classification of the errors encountered during program testing is given along with error rates and program limitations.

Man vs. Machine Comparison

The method by which the performance of the recognition program should be evaluated is open to question. To base the evaluation strictly on a comparison of human recognition versus machine recognition of a Morse code transmission is unfair. The following excerpts from Gold's paper (Ref 4:18) makes this point very clear:

> Morse code is itself not a language but a way of representing or coding a given language, such as English or German. It is analogous to handwriting in that there is a symbol for each character in an alphabet.
> Some people write very clearly so that anyone can read their writing and, further, even those who cannot understand the language of the clear writer may still be able to understand and reproduce each symbol (letter of the alphabet) that was written. It is, however, very helpful to know the language being written; in fact, it is usually more difficult to read handwriting in a foreign language, even if this language is somewhat familiar, than to read one's native language in the same handwriting. Thus we see that, for handwriting, knowledge of the code

> is sometimes (in the case of the clear writer) sufficient to discern each intended symbol; in many cases, a high knowledge, i.e., of the language, is necessary to do so. Note that understanding of the meaning is not being discussed, but merely the identification, symbol for symbol, of what was written. ...it was noted that a man, who knows Morse code, will never remember a sample of data as accurately as a machine; yet he decodes a Morse message well enough to make any machine thus far built turn green with envy. Why? The answer can only be that to a very great extent he knows what to expect because he knows Morse code and the language being sent.

Thus we see that man's knowledge of the language being sent give him a tremendous advantage over a machine, unless the machine has a similar knowledge of the language. The machine described in this project does not have this knowledge and should not be evaluated on a strict man versus machine basis.

However, it is permissable to evaluate performance on a man versus machine-plus-man basis. That is, compare man's ability to recognize a Morse message with man's ability to interpret the message recognized by the machine. Again, man has the decided edge in this comparison. However, man must be able to interpret the output of the machine or the machine is of no value at all. The following excerpt from Gold's paper (Ref 4:22) gives his point of view on this subject:

> It is felt that the effectiveness of a machine... depends on the percentage of received messages that it can adequately decode. The word "adequately" pinpoints the vagueness of this statement; this is interpreted to mean "capable of reconstruction in a reasonable length of time;" even here the problem becomes too subjective.

Testing Procedure

The performance of the recognition program was evaluated in the

following manner. Tape recordings of hand-sent Morse code transmissions were used as the input signal to the machine. These tapes contain examples of messages transmitted by hand key, semi-automatic key ("bug"), electronic keyer, and machine. The type of messages recorded include plain text and code groups. Transmission speeds vary from 7 words per minute (wpm) to 35 wpm. In all, seven different recording sessions were used to evaluate machine performance. Table IV lists the key features and error rates for each recording session.

A 550-word plain text was used as the transmitted message for Recording Sessions 1 through 4. The prepared text and the recognition program printout for each of these recording sessions is contained in Appendix D, Figures D-1 through D-5. On all but Recording Session 4, a copy of the prepared text was given to two people listening to the Morse code transmission. These people annotated their copy to indicate transmission mistakes made by the sender. The two annotated copies were then used to identify recognition program errors (i.e., discrepancies between the prepared text and the machine output) due to the sender and not the machine itself. The remaining errors were used to approximate machine error rate percentages.

All recognition program errors, whether due to sender error or the machine itself, have been classified and are presented in the following section.

Classification of Errors

A classification of the errors encountered in recognition program translations of hand-sent Morse code plain text transmissions is now presented.

TABLE IV

Recording Session Variables and Error Rates

Recording Session	Sending Unit	Transmission Rate (wpm)	Type of Message	Character Errors/ Characters Sent	Error Percentage	Remarks
1	"Bug"	16	Plain Text	$8^{a}/2927$	0.273	Sending Unit Malfunction
2	Hand Key	12	Plain Text	$5^{a}/2927$	0.171	
3	"Bug"	18	Plain Text	$43^{a}/2927$	1.47	Sending Unit Malfunction
4	Electronic Keyer	35	Plain Text	$45^{b}/2927$	1.53	
5	Electronic Keyer	7	Plain Text/ Code Groups	$0^{b}/825$	0.00	
6	Machine	18	Plain Text	$44^{b}/633$	6.9	Radio Broadcast Interference and Signal Fading
7	Hand Key	8-10-12	Code Groups	$3^{b}/914$	0.33	"white" noise

a Machine errors only
b Total errors

1) Two Characters run together. Examples: ME $\rightarrow$ G, TH $\rightarrow$ 6, NA $\rightarrow$ X. Caused by too short a space separating the characters.

2) Split characters. Examples: Y $\rightarrow$ TW, V $\rightarrow$ ST. Caused by too long a space separating pulses within a character.

3) Extra DOT (valid code). Examples: W $\rightarrow$ AA, Y $\rightarrow$ TU, C $\rightarrow$ ND. Caused by transmission of an extra DOT. The resulting character, in this case, is not a valid one. The two printed characters are the product of the Error Correction routine.

5) Missing DOT (valid code). Examples: H $\rightarrow$ S, C $\rightarrow$ K, R $\rightarrow$ A. Caused by absence of a required DOT.

6) Missing DOT (invalid code). Examples: Period $\rightarrow$ AK or CT, 9 $\rightarrow$ MM. Caused by absence of a required DOT resulting in an invalid code. The two printed characters are a result of the Error Correction routine.

7) Simple pulse errors. Examples: Y $\rightarrow$ TU, K $\rightarrow$ O, C $\rightarrow$ B. Caused by an extra-long DOT being recognized as a DASH, or an extra-short DASH being recognized as a DOT. Occurs most frequently when a hand key is used. One or two characters may be printed, depending on whether the resulting internal code word is valid or not.

8) Complex pulse errors. Examples: B $\rightarrow$ K, O $\rightarrow$ X, B $\rightarrow$ M. Caused by two or more DOTs, spaced closer together than usual, being recognized as a DASH. Also caused by a DASH being broken up into two or more DOTs. Occurs most frequently in the presence of input signal noise.

9) Space errors. Examples: all run-on or split words. Caused by either too short a WORD space or too long a CHARACTER space,

respectively. Consistant run-on or split words are caused by an incorrect CHARACTER-WORD Space Adjustment control knob setting.

10) <u>Complex errors</u>. Indicated by the error symbol (=) printout. The source of these errors cannot be traced. The invalid code, resulting from an unknown source, could not be corrected by the Error Correction routine.

Errors of the type 3) through 6) occurred most frequently when a semiautomatic key was used. This can be explained by noting that the number of DOTs transmitted in succession is a function of how long the DOT lever is depressed on these types of sending units. Occasionally the sender, through fatigue or carelessness, sends too many or too few DOTs by not depressing the lever for the correct amount of time.

Error type 8) occurred quite frequently during Recording Sessions 1 and 3. The cause of these errors was traced to improper adjustment of the DOT-sending portion of the "bug" used for both transmissions. Indeed, both recording sessions had to be stopped several times to allow readjustments to be made on the sending unit. Noise induced by contact bounce as a result of the malfunctioning unit was the primary cause of the type 8) errors experienced.

Recording Session 3 contained many type 2) errors. In almost every instance where a V (• • • -) was transmitted, the recognition program printed an S (• • •) T (-) instead. The SYMBOL space following the third DOT was misinterpreted as a CHARACTER space by the machine. Fig. 3-4 (Chapter III) reveals the cause of these machine errors. Notice that the DOT-SYMBOL cluster extends above the SYMBOL linear decision boundary, and that the SYMBOL space variance is much larger in this cluster than it is in corresponding clusters for Recording Sessions

1 and 2 (Figures 3-2 and 3-3 respectively).

There are two possible explanations for this abnormally large SYMBOL space variance: 1) "bug" contact bounce causing the time duration of the last automatically generated DOT to be shorter than usual and, correspondingly, the time duration of the following space to be longer than usual, and 2) too fast a transmission rate setting on the automatic DOT generator, as compared to the actual transmission rate of the message itself. The latter of these two possible explanations is the most feasible, since the DOT portion of the "bug" had a very restricted transmission rate adjustment range over which it would satisfactorily operate. In fact, readjustment was required several times during the 30-minute transmission period. It is quite possible, then, that the actual transmission rate used was too fast, i.e., faster than the rate of the manually transmitted portion of the message. Under these circumstances, the time duration of automatically generated SYMBOL spaces would be shorter than the time duration of manually generated SYMBOL spaces, thereby accounting for the wide time duration variance, and the resulting abundance of type 2) errors.

Analysis of Performance

Recognition program performance was analyzed by comparing the printouts obtained for Recording Sessions 1, 2, and 3 with the annotated worksheets provided by the human receivers. Errors identified on the worksheets were marked on the corresponding machine printout to eliminate them from consideration in the error analysis. These errors are marked with an asterisk on the machine printouts shown in Appendix D. The remaining discrepancies contained in the machine printouts were noted

and used to compute the error rate percentages given below. These errors are marked with a number symbol (#) on the printouts.

Error Rates. The error rates calculated for Recording Sessions 1, 2, and 3 by the previously described method are given in Table IV. Note that error rates are given for character errors only. Space errors causing run-on or split words, although having an effect on the readability of the message, are not considered essential to the overall performance of the recognition program. Character error rate percentages were calculated by dividing the number of incorrect characters noted on the machine printout by the total number of characters in the transmitted message.

The error rate indicated for Recording Session 4 was calculated by dividing all the "uncorrected" character errors by the total number of characters transmitted. "Uncorrected" errors are those machine printout errors occurring in words which were not retransmitted by the operator. During this transmission, the operator followed the standard practice of retransmitting words in which a mistake was made and noted by the operator. The error rates for Recording Sessions 5, 6, and 7 were calculated by dividing all machine printout errors by the number of characters transmitted.

It is interesting to note that many errors annotated by the human receivers did not occur on the machine printout. This, of course, is due mainly to the Error Correction feature of the recognition program. The Error Correction routine was used a total of 15 times during Recording Session 1, 5 times during Recording Session 2, and 5 times during Recording Session 3.

Limitations. Recording Sessions 4 through 7 provide a means of

determining the operational limitations of the recognition program. Knowledge of these limitations is necessary to determine the weak points of the program and to try to correct them.

In general, the recognition program performs well for all types of Morse code transmissions. The major weakness is input signal noise; especially interference having a time duration large enough to alter the DOT, DASH, and pulse averages used by the program to establish linear decision boundaries in two-dimensional pattern space. Although the respective pulse averages do return to their correct values when the interference subsides, the program output during the interference period is, in most cases, unintelligible.

A brief discussion on the results obtained for Recording Sessions 4 through 7 will now be given. Recording Sessions 4 and 5 were transmitted by the same person using the same equipment. Recording Session 4 (Fig. D-5) was transmitted at varying rates ranging from the individual's maximum rate of 35 wpm to a low of approximately 15 wpm. Most of the text was transmitted at the 35 wpm rate. The operator, by his own admission, was sending at his maximum capability and made many mistakes, not all of which were noticed and corrected by the repetition procedure previously described.

Recording Session 5 (Fig. D-6) consists of sentences and code groups used in teaching Morse code to a group of students. With the exception of one sentence, all transmissions were sent one character at a time at a steady 7 wpm rate. This explains the spaces appearing between each character on the machine printout. No machine errors occurred during this recording session.

Recording Session 6 (Fig. D-8) is a radio broadcast of an American

Radio Relay League W1AW cw bulletin, transmitted by machine at 18 wpm. A copy of the transmitted bulletin is shown in Appendix D, Fig. D-7. Much interference and signal fading occurred during this recording session, although not severe enough to prevent a human from correctly copying the message. These disturbances, however, had a great affect on the performance of the machine, as is indicated on the machine printout.

Recording Session 7 (Fig. D-9) consists of code groups transmitted at 8, 10, and 12 wpm on a hand key. These transmissions were obtained from tape recordings of hand-sent Morse code used by the U.S. Army to teach Morse code during WWII. The tapes contained a background "white" noise which did not, as the machine output shows, affect recognition program performance.

Analysis of all results obtained from the seven recording sessions indicates that the recognition program is capable of recognizing hand-sent Morse code at speeds up to at least 35 wpm with moderate signal noise. The main limitation thus far discovered in this project is pulse-type interference.

VII. Conclusions and Recommendations

This chapter presents the conclusions reached from the limited testing performed on the recognition program. Also, recommendations concerning further testing procedures and possible program changes are given.

Conclusions

Although only seven different types of Morse code transmissions were used to evaluate the performance of the recognition program, the results obtained clearly define the attributes and weaknesses of the program in its present form. Certainly more work must be done on the Signal Processing section to limit the detrimental effects of input signal pulse-type interference, since signal interference is prevalent on the radio bands used for cw transmissions. Perhaps a simpler algorithm than that of the low-pass digital filter technique used in the program will produce better results. A combination of digital filtering and other noise reduction techniques might prove to be optimum.

Aside from the interference problem, the performance of the recognition program is very satisfactory. The character error rates calculated for Recording Sessions 1, 2, and 3 are well within an acceptable limit. The readability of the machine output, a function of the particular sender, is optimizable by real-time adjustment. Since it is desirable to have the machine operate with as little human intervention as possible, preferably none, procedures are given in the next section to automate the readability adjustment as well as certain other controls now requiring real-time adjustments to maximize performance.

These procedures and recommendations are now presented.

Recommendations

The recommendations presented in this section deal with recognition program improvements and hardware realization suggestions.

Recognition Program Improvements. The recognition program, in its present form, represents an attempt to perform machine recognition of hand-sent Morse code by methods other than those previously documented. Admittedly, when the project was undertaken there was no guarantee that the techniques used in this program would be as good as or better than those other methods.

The use of averaging algorithms can be very misleading. Extreme care must be exercised when trying to fit an averaging technique to a particular physical phenomenon. For example, the average human being has one testicle and half a uterus. Basing decisions on this type of average is certainly absurd. However, the distribution properties of hand-sent Morse code indicate that averaging techniques are indeed applicable. Test results confirm this conclusion.

Unfortunately, the use of averaging techniques presents a problem when pulse-type interference is present in the input signal. Interference of this type offsets the pulse averages used in the program. One possible solution to this problem is the establishment of upper and lower bounds around the DOT and DASH averages computed in the program. Data distribution plots indicate a relatively tight grouping of DOT and DASH time durations for a particular sender. These time durations may be assumed to have a normal distribution with a mean approximated by the calculated averages (Ref 3:27). A 2-sigma confidence interval can easily

be established and used to exclude time durations not within this interval from the averaging process. This method should be capable of detecting time duration average differences present in a two-way conversation. The data distribution plots reveal that time duration intervals remain within a 2-sigma interval of each other for transmission rates between 10 and 20 wpm. Quite possibly this overlap exists for an even larger difference in transmission rates. It is recommended that additional data be obtained to confirm or deny this possibility.

The human intervention now required to optimize readability of the machine printout can easily be eliminated by an additional program routine. The number of spaces printed on each line of machine output can be compared with an upper and lower limit to determine whether adjustment is needed. For example, if the number of spaces printed exceeds 15, the CHARACTER-WORD space adjustment should be increased; if the number of spaces is less than 5, the adjustment should be decreased. The amount of readjustment per change can be optimized to prevent over correction while still allowing the optimum value to be reached within a reasonable amount of time. The upper and lower limits and the incremental adjustment value must be determined experimentally.

Human intervention now necessary to optimize the number of input signal samples to be averaged for the change detection process can also be replaced by computer programming. An initial value, preset at the start of the program, can be adjusted to an optimum value as a function of the DOT average. For example, the value can be adjusted to filter out all pulses having a time duration of less than one half the DOT average. The low-pass cut-off frequency of the digital filter is determined by the number of samples averaged and the interrupt frequency.

Since the interrupt frequency is a constant, set at the maximum value permitting proper Code Translation section operation, the relationship between number of samples and cut-off frequency is linear. The number of samples to be averaged is thus directly proportional to the DOT average. The actual relationship must be determined experimentally.

Hardware Realization. Many of the peripheral devices and control knobs used in this project can be eliminated in a hardware realization of the recognition program. The input signal threshold level can be set at a constant value of $+777_8$, thereby eliminating the threshold control knob. A feedback control circuit can be used to regulate the peak dc voltage of the rectified input signal to an optimum value for the constant threshold. Inclusion of the program changes recommended in the previous section would eliminate the need for sample number and readability control knobs. It may be desirable, however, to retain these controls to permit human intervention if required under unusual circumstances. The two switches used to perform a program restart can be replaced by one START/RESET pushbutton.

The entire program, now requiring about 3K of memory, can easily be reduced to fit within a 1K 12-bit memory unit by elimination of those instructions now used to control the CRT Display and sample switches. Elimination of these instructions has the added benefits of faster program execution time, better reliability, and less construction cost.

The use of a 16-bit structure will provide additional programming capabilities not possible with the 12-bit structure of the PDP-12 computer. First of all, a constant Real Time Clock frequency can be used for all Morse code transmission rates, since the 16-bit word length will provide a 65,536 (2^{16}) clock counter overflow range. For example, an external

clock frequency of 65,536 Hz will permit recognition of pulse and space time durations ranging from 1 or 2 milliseconds to one second in length. This corresponds to transmission rates in the range of 5 to 500 wpm.

The 16-bit structure will also permit increased error correction capability. The 12-bit structure used in the recognition program permits error correction of a run-on Morse characters not exceeding 8 pulses in length. The 16-bit structure will permit correction of run-on characters up to 12 pulses in length. Effective use of this increased capability will require revision of the Error Correction routine to allow for the possibility of three run-on characters.

BIBLIOGRAPHY

1. American Radio Relay League. The Radio Amateur's Handbook (Forty-Seventh Edition). Newington, Conn.: American Radio Relay League, Inc., 1970.

2. Digital Equipment Corporation. PDP-12 System Reference Manual (Fourth Printing). Maynard, Mass.: Digital Equipment Corporation, October 1971.

3. Freimer, M., B. Gold, and A.L. Tritter. "The Morse Distribution." Institute of Radio Engineers Transactions on Information Theory, 1:25-31 (March 1959).

4. Gold, B. "Machine Recognition of Hand-Sent Morse Code." Institute of Radio Engineers Transactions on Information Theory, 1:17-24 (March 1959).

5. Petit, R.C. "The Morse-A-Verter - Copying Morse Code by Machine." QST Vol. LV Number 1:30-35 (January 1971).

6. Powers, B.L., and F.R. Scalf. The Design of a Morse-to-Teletype Signal Converter Using Integrated Micrologic Circuitry. Unpublished thesis. United States Naval Postgraduate School, June 1968.

7. Ullman, J.R. Pattern Recognition Techniques New York: Crane, Russak and Co., Inc., 1973.

8. West, L.J. Review of Research on Morse Code Learning - Summary of Findings and Recommendations. Technical memorandum. Chanute Air Force Base, Illinois: Training Aids Research Laboratory, November 1968.

Appendix A

Recognition Program Listing

The Recognition Program was written for use on the PDP-12 computer equipped with a CRT Display, Teletype or DECWRITER, KW12-A Real Time Interface, Data Terminal, and a TU56 Dual Drive Transport. The program is written in LAP6-DIAL assembly language.

The listing contains six columns of information. These are, from left to right, program line number, memory field location, octal value assigned to the location, user-assigned symbols, program and assembly instructions or data, and comments.

```
                    *20
                    /      HAND SENT MORSE CODE
                    /      RECOGNITION PROGRAM
                    /
                    /
                    /
                    /
                              PMODE
                              *0
0000  0000                    0                /PMODE
0001  5402                    JMP I 2          /INTERUPT
0002  0233                    SERVE
                              *5
0005  0000                    0
0006  0000                    0
0007  0000                    0
0010  0000                    0
0011  6000          SIGNAL,   6000
0012  0577          STORE,    577
0013  0577          WORD,     577
0014  4017          STORIT,   4017             /ASCII MEMORY
                              *17
0017  7767                    7767
                              *20
0020  0000          CHECK,    0
0021  0000          NUM,      0
0022  0000          COUNT,    0
0023  0400          SADIS0,   SADIS
0024  1200          ADSAM0,   ADSAM
0025  1600          PROCE0,   PROCES
0026  0011          KCLP,     0011
0027  0000          CHANGE,   0
0030  0271          SENSE0,   SENSE
0031  7001          M777,     -777
0032  0577          K577,     577
0033  0000          NUMR,     0
0034  2214          EFL10,    EFL1
0035  2251          EFL20,    EFL2
0036  0000          EFLAG1,   0
0037  0000          EFLAG2,   0
                              LMODE
0040  0000                    0                /LMODE
0041  6221                    JMP SERVEL       /INTERUPT
                              PMODE
0042  2300          SETPT0,   SETPTR
0043  0000          MSTART,   0
0044  0000          WDREG,    0
0045  2400          IPROC0,   IPROC
0046  0000          CODE,     0
0047  3000          C01,      AUNK
0050  3014          C02,      A5
0051  3026          C11,      ASPAC
0052  3036          C21,      AU
```

```
0053   3044   C22,     AWAIT
0054   3052   C31,     A
0055   3062   C41,     W
0056   3072   C42,     A6
0057   3102   C51,     T
0060   3114   C61,     K
0061   3122   C62,     A7
0062   3130   C71,     M
0063   3134   C72,     A9


0064   3202   CHKIT,   CHCK
0065   3013   CN5,     N5
0066   3043   CWAIT,   WAIT
0067   3071   CN6,     N6
0070   3121   CN7,     N7
0071   3133   CN9,     N9
0072   2607   ASC0,    ASCII
0073   1602   PRCAG0,  PRCAGN
0074   7700   KLINE,   7700
0075   7700   LINE,    7700
0076   0000   IWFLAG,  0
0077   7777   M1,      -1
0100   0001   K1,      1
0101   1777   K1777,   1777
0102   0000   PX,      0
0103   7140   M640,    -640
0104   0000   DOTAV,   0
0105   0000   DASHAV,  0
0106   0000   PAVG,    0
0107   0000   FUDGE,   0
0110   0000   SAFUDG,  0
0111   0000   HOLDWD,  0
0112   0377   K377,    377
0113   0000   TEMP,    0
0114   0240   K240,    240
0115   0215   K215,    215
0116   0212   K212,    212
0117   0100   RATE0,   0100
0120   0000   CWAVG,   0
0121   0013   K13,     13
0122   7776   M2,      -2
0123   7776   KM2,     -2
0124   2050   PWD0,    PWD
0125   2200   ICODE0,  ICODE
0126   0217   RSTAR0,  RSTART
0127   6000   K6000,   6000
0130   0000   PFLAG,   0
0131   0000   KCHANG,  0
0132   0430   CONDI0,  CONDIS
0133   2000   SDASH0,  SDASH
0134   2254   DIAL0,   DIAL
0135   0777   K777,    777
```

```
0136 7777  PAST,   7777             /INTL VAL = -1
0137 0000  THRESH, 0
0140 1443  AOUT0,  AOUT
0141 1404  RESET0, RESET
0142 1400  TIMER0, TIMER
0143 1332  ADSAM1, ADSAM2
0144 0000  NEW1,   0
0145 0000  PORS,   0
0146 0000  WHICH,  0
0147 0000  TIME,   0
0150 0000  IWF1,   0
0151 0000  IWF2,   0
0152 0000  NUM31,  0
0153 0000  NUM32,  0
0154 4017  KSTOR,  4017
0155 0000  UNFLG,  0
0156 0000  UNCK1,  0
0157 0000  UNCK2,  0
0160 0000  UNCK3,  0
0161 0000  ERWDNM, 0
0162 3400  UNKCH0, UNKCHK


0163 0000  TEMPMN, 0
0164 0000  MNUM,   0
0165 0000  LMNUM,  0
0166 1500  FIG10,  FIG1
0167 3467  RFIG10, RFIG1
0170 1516  FIG20,  FIG2
0171 3600  RFIG20, RFIG2
0172 0000  TALLY,  0
0173 0000  TALLY1, 0
0174 0000  TALLY2, 0
0175 2404  IPRTN0, IPRTN
0176 1723  CALSP0, CALSPA
0177 0000  CDE32,  0
                   SHL=7413
                   CAM=7621
           /
           /
                   LMODE
                   KCC=6032
                   KSF=6031
                   RMF=6244
                   ION=6001
           /
           /
                   PMODE
           /
           /
           /
           /
           /
```

```
                        *200
0200  7300  START,      CLA CLL
0201  1127              TAD K6000
0202  6132              CLLR                /EXTNL CLK RATE
0203  7200              CLA
0204  1322              TAD CFLAG
0205  6134              CLEN                /ENABLE INPUT 1
0206  7200              CLA
0207  6046              TLS
0210  6032              KCC
0211  6141              LINC
                        LMODE
0212  1020              LDA I
0213  0240              0240
0214  0004              ESF                 /FULL SZ DSPLY &
0215  0002              PDP                 /DSABL TTY INTRP
                        PMODE
0216  4442              JMS I SETPT0        /CR + 2 LFS
0217  4423  RSTART,     JMS I SADIS0        /SET AD SMPL SIZ
0220  5425              JMP I PROCE0        /GO TO MAIN PROG
            /
            /
            /
            /
            /  INTERUPT SERVICE ROUTINE
            /
            /
                        LMODE
0221  4325  SERVEL,     STC AC              /SAVE AC
0222  0261              ROL I 1
0223  4323              STC LINK            /SAVE LINK
0224  2040              ADD 0040            /GET RTN ADDRSS
0225  1620              BSE I

0226  6000              6000
0227  4270              STC LRTN            /CREATE RTN JMP
0230  2100              ADD K1
0231  4326              STC LFLAG           /SET LFLAG
0232  6241              JMP LCONT
                        PMODE
0233  3325  SERVE,      DCA AC              /STORE AC VALUE
0234  7204              GLK
0235  3323              DCA LINK            /STORE LINK
0236  1000              TAD 0000
0237  3324              DCA HOLDIN          /STORE PC
0240  6141              LINC
                        LMODE
0241  0643  LCONT,      LDF 3               /SET DF = 3
0242  0002              PDP
                        PMODE
0243  4424              JMS I ADSAM0        /YES GO TO ADSAM
0244  7300  EXIT,       CLA CLL
```

```
0245  1326          TAD LFLAG
0246  7640          SZA CLA           /LFLAG SET?
0247  5257          JMP LOUT          /YES
0250  1323          TAD LINK          /NO
0251  7010          RAR               /RESTORE LINK
0252  1324          TAD HOLDIN
0253  3000          DCA 0000          /RESTORE PC
0254  1325          TAD AC            /RESTORE AC
0255  6001          ION               /INTERUPT ON
0256  5400          JMP I 0           /RTN TO PROGRAM
0257  3326  LOUT,   DCA LFLAG         /CLEAR LFLAG
0260  6141          LINC
                    LMODE
0261  0011          CLR
0262  2323          ADD LINK
0263  0321          ROR I 1           /RESTORE LINK
0264  2325          ADD AC            /RESTORE AC
0265  0006          DJR
0266  0500          IOB
0267  6001          ION               /INTERUPT ON
0270  0000  LRTN,   0
                    PMODE
            /
            /
            /
            /
            /  SENSE SWITCH ROUTINE
            /
            /  SENSE SW 1 = DUMP MEMORY & RESTART
            /  SENSE SW 2 = DUMP MEMORY & GO TO DIAL
            /
            /
0271  0000  SENSE,  0
0272  6141          LINC
                    LMODE
0273  0461          SNS I 1           /SENSE SW 1 SET?
0274  6301          JMP SW1           /YES
0275  0462          SNS I 2           /NO  SW 2 SET?
0276  6306          JMP SW2           /YES
0277  0002          PDP               /NO
                    PMODE
0300  5671          JMP I SENSE
                    LMODE
0301  0002  SW1,    PDP
                    PMODE

0302  7200          CLA
0303  7001          IAC
0304  3036          DCA EFLAG1        /SET SW1 FLAG
0305  5312          JMP EMPTY
                    LMODE
0306  0002  SW2,    PDP
```

```
                        PMODE
0307  7300              CLA CLL
0310  7001              IAC
0311  3037              DCA EFLAG2        /SET SW2 FLAG
0312  7100  EMPTY,      CLL
0313  1323              TAD LINK
0314  7010              RAR               /RESTORE LINK
0315  1324              TAD HOLDIN
0316  3000              DCA 0000          /RESTORE PC
0317  1325              TAD AC            /RESTORE AC
0320  6244              RMF               /RESTORE IF & DF
0321  5400              JMP I 0
            /
            /
0322  0020  CFLAG,      0020
0323  0000  LINK,       0
0324  0000  HOLDIN,     0
0325  0000  AC,         0
0326  0000  LFLAG,      0
            /
            /
            /
            /  AD SAMPLE & DISPLAY ROUTINE
            /
            /
                        *460
0400  0000  SADIS,      0
0401  6141              LINC
                        LMODE
0402  0011              CLR
0403  2001              ADD 0001
0404  4526              STC HOLD          /SAVE PI JMP
0405  0011  AGNDS,      CLR
0406  0112              SAM 12            /SMPL INPUT SGNL
0407  1560              BCL I
0410  7000              7000
0411  4530              STC SIG           /STORE INPUT
0412  2137              ADD THRESH
0413  2122              ADD M2
0414  0017              COM
0415  2530              ADD SIG
0416  0451              APO               /PULSE OR SPACE?
0417  0467              SKP               /SPACE
0420  6425              JMP P3            /PULSE
0421  0011              CLR
0422  2077              ADD M1
0423  1071              STA I SIGNAL      /STORE -1
0424  6430              JMP CONDIS
0425  0011  P3,         CLR
0426  2100              ADD K1
0427  1071              STA I SIGNAL      /STORE +1
0430  0011  CONDIS,     CLR
0431  0101              SAM 1             /GET SAMPLE NBR
0432  4022              STC COUNT
```

```
0433  0100      SAM 0          /SMPL THRESHOLD
0434  4137      STC THRESH
0435  2531      ADD M377

0436  2137      ADD THRESH
0437  0166      DIS I 6        /DSPLY THRESHOLD
0440  0011      CLR
0441  2531      ADD M377
0442  2530      ADD SIG
0443  0167      DIS I 7        /DSPLY INPUT
0444  0011      CLR
0445  4001      STC 0001       /CLEAR 0001
0446  2022      ADD COUNT
0447  1560      BCL I
0450  0777      0777
0451  0311      ROR 9
0452  4033      STC NUMR       /GET FIRST BIT
0453  7001      JMP DISCPY     /DISPLAY IT
0454  2022      ADD COUNT
0455  1560      BCL I
0456  7077      7077
0457  0306      ROR 6
0460  4033      STC NUMR       /GET SECOND BIT
0461  7001      JMP DISCPY     /DISPLAY IT
0462  2022      ADD COUNT
0463  1560      BCL I
0464  7707      7707
0465  0303      ROR 3
0466  4033      STC NUMR       /GET THIRD BIT
0467  7001      JMP DISCPY     /DISPLAY IT
0470  2022      ADD COUNT
0471  1560      BCL I
0472  7770      7770
0473  4033      STC NUMR       /GET FOURTH BIT
0474  7001      JMP DISCPY     /DISPLAY IT
0475  0500      IOB
0476  6031      KSF            /KEYBOARD HIT?
0477  6405      JMP AGNDS      /NO
0500  0500      IOB            /YES
0501  6032      KCC
0502  2527      ADD MAIND0
0503  1620      BSE I
0504  6000      6000           /CREATE JMP
0505  4430      STC CONDIS
0506  2022      ADD COUNT
0507  1660      BCO I
0510  7777      7777
0511  2100      ADD K1         /FORM 2S COMP
0512  4131      STC KCHANG     /OF COUNT
0513  2131      ADD KCHANG
0514  4027      STC CHANGE
0515  2027      ADD CHANGE
```

```
0516   2027                ADD CHANGE
0517   2123                ADD KM2
0520   4020                STC CHECK          /TWICE KCHANG
0521   0011   MAINDS,      CLR
0522   2526                ADD HOLD
0523   4001                STC 0001           /RESTORE PI
0524   0002                PDP                /JMP INSTR
                           PMODE
0525   5600                JMP I SADIS
              /
              /
0526   0000   HOLD,        0
0527   0521   MAIND0,      MAINDS
0530   0000   SIG,         0
0531   7401   M377,        -377

              /
              /
              /
              /
              /  CHARACTER DISPLAY ROUTINE
              /
              /
                           *1000
1000   0000                0                  /SENSE SW1 STORE
                           LMODE
1001   0011   DISCPY,      CLR
1002   2000                ADD 0000
1003   5114                STC HOLDRN         /SAVE JMS RTN
1004   2033                ADD NUMR
1005   0470                AZE I              /NUMR = 0?
1006   7061                JMP NUM0           /YES
1007   2123                ADD KM2            /NO
1010   0470                AZE I              /NUMR = 1?
1011   7067                JMP NUM1           /YES
1012   2123                ADD KM2            /NO
1013   0470                AZE I              /NUMR = 2?
1014   7075                JMP NUM2           /YES
1015   2123                ADD KM2            /NO
1016   0470                AZE I              /NUMR = 3?
1017   7103                JMP NUM3           /YES
1020   2123                ADD KM2            /NO
1021   0470                AZE I              /NUMR = 4?
1022   7037                JMP NUM4           /YES
1023   2123                ADD KM2            /NO
1024   0470                AZE I              /NUMR = 5?
1025   7045                JMP NUM5           /YES
1026   2123                ADD KM2            /NO
1027   0470                AZE I              /NUMR = 6?
1030   7053                JMP NUM6           /YES
1031   0011                CLR                /NO NUM = 7
1032   1760                DSC I
```

```
1033  4443             4443
1034  1760             DSC I
1035  6050             6050            /DISPLAY 7
1036  7110             JMP DISOUT
1037  0011  NUM4,      CLR
1040  1760             DSC I
1041  2414             2414
1042  1760             DSC I
1043  0477             0477            /DISPLAY 4
1044  7110             JMP DISOUT
1045  0011  NUM5,      CLR
1046  1760             DSC I
1047  5172             5172
1050  1760             DSC I
1051  0651             0651            /DISPLAY 5
1052  7110             JMP DISOUT
1053  0011  NUM6,      CLR
1054  1760             DSC I
1055  1506             1506
1056  1760             DSC I
1057  4225             4225            /DISPLAY 6
1060  7110             JMP DISOUT
1061  0011  NUM0,      CLR
1062  1760             DSC I
1063  4136             4136
1064  1760             DSC I
1065  3641             3641            /DISPLAY 0

1066  7110             JMP DISOUT
1067  0011  NUM1,      CLR
1070  1760             DSC I
1071  2101             2101
1072  1760             DSC I
1073  0177             0177            /DISPLAY 1
1074  7110             JMP DISOUT
1075  0011  NUM2,      CLR
1076  1760             DSC I
1077  4523             4523
1100  1760             DSC I
1101  2151             2151            /DISPLAY 2
1102  7110             JMP DISOUT
1103  0011  NUM3,      CLR
1104  1760             DSC I
1105  4122             4122
1106  1760             DSC I
1107  2651             2651            /DISPLAY 3
1110  0011  DISOUT,    CLR
1111  3114             ADD HOLDRN
1112  4000             STC 0000        /RESTORE RTN
1113  6000             JMP 0
            /
            /
```

```
1114  0000  HOLDRN,  0
                     PMODE
            /
            /
            /
            /
            /  AD SAMPLE DECISION ROUTINE
            /
            /
                     *1200
1200  0000  ADSAM,   0
1201  4423           JMS I SADIS0      /SMPL & DSPLY
1202  7200           CLA
1203  2027           ISZ CHANGE        /N SAMPLES YET?
1204  5600           JMP I ADSAM       /NO
1205  1146           TAD WHICH         /YES
1206  7440           SZA               /CHANGE OR CHK?
1207  5246           JMP ENDCHK        /END OF CHECK
1210  1127           TAD K6000         /END OF CHANGE
1211  3011           DCA SIGNAL        /RESET MEMORY
1212  1131           TAD KCHANG
1213  3027           DCA CHANGE        /RESET SMPL NBR
1214  1411           TAD I SIGNAL
1215  2027           ISZ CHANGE
1216  5214           JMP .-2           /ADD SMPLD INPTS
1217  7700           SMA CLA           /PULSE OR SPACE?
1220  5224           JMP P1            /PULSE
1221  1077           TAD M1            /SPACE
1222  3144           DCA NEW1          /STORE -1
1223  5227           JMP COMP
1224  7200  P1,      CLA
1225  7001           IAC
1226  3144           DCA NEW1          /STORE +1
1227  1127  COMP,    TAD K6000
1230  3011           DCA SIGNAL        /RESET MEMORY
1231  1136           TAD PAST          /COMPARE WITH
1232  1144           TAD NEW1          /PREVIOUS VALUE
1233  7650           SNA CLA           /CHANGE?
1234  5241           JMP .+5           /YES

1235  1131           TAD KCHANG        /NO
1236  3027           DCA CHANGE        /RESET CHANGE
1237  4430           JMS I SENSE0      /CHK SNS SWS
1240  5600           JMP I ADSAM       /RTN TO PROG
1241  1020           TAD CHECK
1242  3027           DCA CHANGE        /SET SMPL NBR
1243  1100           TAD K1
1244  3146           DCA WHICH         /SET FLAG
1245  5600           JMP I ADSAM
1246  7200  ENDCHK,  CLA
1247  1127           TAD K6000
1250  3011           DCA SIGNAL        /RESET MEMORY
```

```
1251 1020         TAD CHECK
1252 3027         DCA CHANGE       /RESET SMPL NBR
1253 1411         TAD I SIGNAL
1254 2027         ISZ CHANGE
1255 5253         JMP .-2          /ADD SMPLD INPTS
1256 7700         SMA CLA          /PULSE OR SPACE?
1257 5263         JMP P2           /PULSE
1260 1077         TAD M1           /SPACE
1261 3144         DCA NEW1         /STORE -1
1262 5266         JMP COMP1
1263 7200 P2,     CLA
1264 1100         TAD K1
1265 3144         DCA NEW1         /STORE +1
1266 1127 COMP1,  TAD K6000
1267 3011         DCA SIGNAL       /RESET MEMORY
1270 1136         TAD PAST
1271 1144         TAD NEW1
1272 7440         SZA              /PERMANENT CHG?
1273 5540         JMP I AOUT0      /NO
1274 1136         TAD PAST         /YES
1275 3145         DCA PORS         /SET P/S FLAG
1276 1144         TAD NEW1
1277 3136         DCA PAST         /SET NEW LEVEL
1300 6141         LINC
                  LMODE
1301 0101         SAM 1            /SAMPLE COUNT
1302 4022         STC COUNT
1303 0100         SAM 0            /SMPL THRESHOLD
1304 4137         STC THRESH
1305 0104         SAM 4            /SAMPLE FUDGE
1306 4107         STC FUDGE
1307 2107         ADD FUDGE
1310 2107         ADD FUDGE
1311 2107         ADD FUDGE
1312 4107         STC FUDGE
1313 0002         PDP
                  PMODE
1314 1022         TAD COUNT        /GET LATEST
1315 7041         CIA              /SAMPLE NBR
1316 3131         DCA KCHANG
1317 1131         TAD KCHANG
1320 3027         DCA CHANGE       /SET CHANGE NBR
1321 1027         TAD CHANGE
1322 1027         TAD CHANGE
1323 3020         DCA CHECK        /SET CHECK NBR
1324 6135         CLSA
1325 7700         SMA CLA          /CLOCK OVRFLW?
1326 5542         JMP I TIMER0     /NO GET TIME
1327 7240         STA              /YES
1330 3147         DCA TIME         /SET TIME=7777
1331 5541         JMP I RESET0
```

```
1332  5600  ADSAM2,  JMP I ADSAM
                /
                /
                         *1400
1400  7200  TIMER,   CLA
1401  6133           CLAB
1402  6137           CLCA
1403  3147           DCA TIME          /STORE TIME
1404  6133  RESET,   CLAB
1405  1117           TAD RATE0
1406  6132           CLLR              /CLEAR CLK CNTR
1407  6135           CLSA
1410  7200           CLA
1411  1127           TAD K6000
1412  6132           CLLR              /RESET CLOCK
                /
                /
                /   PREPARE TIME & TYPE OF SIGNAL
                /   FOR STORAGE
                /
                /
1413  7200           CLA
1414  1145           TAD PORS
1415  7700           SMA CLA           /PULSE OR SPACE?
1416  5225           JMP PULSE         /PULSE
1417  1147           TAD TIME          /SPACE
1420  7010           RAR
1421  7100           CLL
1422  7004           RAL               /SET AC 11=0
1423  3412           DCA I STORE       /STORE DATA
1424  5233           JMP AOUT1
1425  7200  PULSE,   CLA
1426  1147           TAD TIME
1427  7010           RAR
1430  7120           STL
1431  7004           RAL               /SET AC 11=1
1432  3412           DCA I STORE       /STORE DATA
1433  1012  AOUT1,   TAD STORE
1434  1031           TAD M777
1435  7440           SZA               /LAST WD OF MEM?
1436  5243           JMP .+5           /NO
1437  1032           TAD K577          /YES
1440  3012           DCA STORE         /RESET MEM LOC
1441  7001           IAC
1442  3043           DCA MSTART        /SET FLAG
1443  7200  AOUT,    CLA
1444  3146           DCA WHICH         /RESET CHG FLAG
1445  1131           TAD KCHANG
1446  3027           DCA CHANGE        /RESET CHANGE
1447  5543           JMP I ADSAM1      /IND RETURN
                /
                /
                /
                         *1500
```

```
1500  6141  FIG1,    LINC
                     LMODE
1501  0011  MNAGN,   CLR
1502  2163           ADD TEMPMN
1503  0241           ROL 1
1504  4163           STC TEMPMN
1505  2164           ADD MNUM
1506  1120           ADA I
1507  0001           0001

1510  4164           STC MNUM
1511  2164           ADD MNUM
1512  0450           AZE              /MNUM = 0?
1513  7501           JMP MNAGN        /NO
1514  0002           PDP              /YES
                     PMODE
1515  5567           JMP I RFIG10
1516  6141  FIG2,    LINC
                     LMODE
1517  0011  ROTAGN,  CLR
1520  2163           ADD TEMPMN
1521  0301           ROR 1
1522  4163           STC TEMPMN
1523  2165           ADD LMNUM
1524  1120           ADA I
1525  0001           0001
1526  4165           STC LMNUM
1527  2165           ADD LMNUM
1530  0451           APO              /LMNUM POSITIVE?
1531  7517           JMP ROTAGN       /NO
1532  0011           CLR              /YES
1533  2163           ADD TEMPMN
1534  1560           BCL I
1535  0077           0077
1536  2153           ADD NUM32
1537  4177           STC CDE32        /2ND CODE WORD
1540  2163           ADD TEMPMN
1541  1560           BCL I
1542  7700           7700
1543  4163           STC TEMPMN
1544  0002           PDP
                     PMODE
1545  5571           JMP I RFIG20
            /
            /
            /
            /
            /
            /  MAIN DATA PROCESSING ROUTINE
            /
            /
                     *1600
```

```
1600  7300  PROCES, CLA CLL        /
1601  4445          JMS I IPROCW   /INITIALIZE
1602  7200  PRCAGN, CLA
1603  1013          TAD WORD
1604  7041          CIA
1605  1012          TAD STORE
1606  7540          SMA SZA        /STORE-WORD>0?
1607  5223          JMP GETNW      /YES
1610  7200          CLA            /NO
1611  1043          TAD MSTART
1612  7440          SZA            /MSTART SET?
1613  5223          JMP GETNW      /YES
1614  1036          TAD EFLAG1     /NO
1615  7440          SZA            /EFLAG1 SET?
1616  5434          JMP I EFL10    /YES
1617  1037          TAD EFLAG2     /NO
1620  7440          SZA            /EFLAG2 SET?
1621  5435          JMP I EFL20    /YES
1622  5202          JMP PRCAGN     /NO
1623  7300  GETNW,  CLA CLL
1624  1413          TAD I WORD

1625  3111          DCA HOLDWD
1626  1111          TAD HOLDWD
1627  3414          DCA I STORIT   /STORE TIME
1630  1014          TAD STORIT
1631  1321          TAD M4050
1632  7640          SZA CLA        /STORIT = 4050?
1633  5236          JMP .+3        /NO
1634  1154          TAD KSTOR      /YES
1635  3014          DCA STORIT     /RESET STORIT
1636  1013          TAD WORD
1637  1031          TAD M777
1640  7440          SZA            /WORD=777?
1641  5245          JMP PORSWD     /NO
1642  1032          TAD K577       /YES
1643  3013          DCA WORD       /RESET WORD
1644  3043          DCA MSTART     /CLEAR MSTART
1645  7300  PORSWD, CLA CLL
1646  1111          TAD HOLDWD
1647  7010          RAR
1650  7430          SZL            /PULSE OR SPACE?
1651  5524          JMP I PWD0     /PULSE
1652  7200          CLA            /SPACE
1653  1102          TAD PX
1654  7440          SZA            /LAST PULSE?
1655  5533          JMP I SDASH0   /DASH
1656  1111          TAD HOLDWD     /DOT
1657  7010          RAR            /COMPARE WITH
1660  3113          DCA TEMP       /AVERAGE
1661  1106          TAD PAVG
1662  7010          RAR
```

```
1663  7041          CIA
1664  1113          TAD TEMP
1665  7710          SPA CLA         /INTER OR INTRA?
1666  5473          JMP I PRCAG0    /INTRA
1667  1120          TAD CWAVG       /INTER
1670  7012          RTR             /COMPUTE NEW
1671  7010          RAR             /CWAVG
1672  0135          AND K777
1673  7041          CIA
1674  3322          DCA CTEMP
1675  1111          TAD HOLDWD
1676  7012          RTR
1677  7010          RAR
1700  0135          AND K777
1701  1322          TAD CTEMP
1702  1120          TAD CWAVG
1703  3120          DCA CWAVG       /NEW CWAVG
1704  1120          TAD CWAVG
1705  1107          TAD FUDGE       /ADD CORRECTION
1706  3110          DCA SAFUDG      /NEW SAFUDG
1707  7100          CLL
1710  1110          TAD SAFUDG
1711  7010          RAR
1712  7041          CIA
1713  1113          TAD TEMP
1714  7710          SPA CLA         /INTER CH OR WD?
1715  5525          JMP I ICODE0    /INTER CHAR
1716  1111          TAD HOLDWD      /INTER WORD
1717  3076          DCA IWFLAG
1720  5525          JMP I ICODE0
                /
1721  3730    M4050,  -4050
1722  0000    CTEMP,  0

                /
                /
1723  7300    CALSPA, CLA CLL   /COMPUTE
1724  1120          TAD CWAVG       /INITIAL
1725  7012          RTR             /CWAVG
1726  0101          AND K1777
1727  7041          CIA
1730  3113          DCA TEMP
1731  1111          TAD HOLDWD
1732  7012          RTR
1733  0101          AND K1777
1734  1113          TAD TEMP
1735  1120          TAD CWAVG
1736  3120          DCA CWAVG       /NEW CWAVG
1737  5575          JMP I IPRTN0
                /
                /
                /
```

```
                        *2000
2000  7300  SDASH,      CLA CLL
2001  1106              TAD PAVG
2002  7041              CIA
2003  1102              TAD PX              /COMPUTE
2004  7012              RTR                 /INTER/INTRA
2005  0101              AND K1777           /SPACE(DASH)
2006  7041              CIA                 /EQUATION
2007  1106              TAD PAVG
2010  7100              CLL
2011  7010              RAR
2012  7041              CIA
2013  3113              DCA TEMP
2014  1111              TAD HOLDWD
2015  7100              CLL
2016  7010              RAR
2017  1113              TAD TEMP
2020  7700              SMA CLA             /INTER OR INTRA?
2021  5223              JMP .+2             /INTER
2022  5473              JMP I PRCAG0        /INTRA
2023  7300              CLA CLL
2024  1106              TAD PAVG
2025  7041              CIA                 /COMPUTE
2026  1102              TAD PX              /INTER CH
2027  7012              RTR                 /OR
2030  0101              AND K1777           /INTER WORD
2031  7041              CIA                 /EQUATION
2032  1110              TAD SAFUDG
2033  7100              CLL
2034  7010              RAR
2035  7041              CIA
2036  3113              DCA TEMP
2037  1111              TAD HOLDWD
2040  7100              CLL
2041  7010              RAR
2042  1113              TAD TEMP
2043  7710              SPA CLA             /CH OR WORD?
2044  5525              JMP I ICODE0        /INTER CH
2045  1111              TAD HOLDWD          /INTER WORD
2046  3076              DCA IWFLAG          /SET IWFLAG
2047  5525              JMP I ICODE0
2050  7200  PWD,        CLA
2051  1021              TAD NUM
2052  7001              IAC
2053  3021              DCA NUM             /INCRMNT NUM

2054  1111              TAD HOLDWD
2055  7041              CIA
2056  1106              TAD PAVG
2057  7700              SMA CLA             /DOT OR DASH?
2060  5320              JMP PDOT            /DOT
2061  7100              CLL                 /DASH
```

```
2062  1111           TAD HOLDWD
2063  7010           RAR
2064  7041           CIA
2065  1105           TAD DASHAV
2066  7700           SMA CLA          /HOLDWD>2DASHAV?
2067  5274           JMP .+5          /NO
2070  1105           TAD DASHAV       /YES
2071  1105           TAD DASHAV
2072  1100           TAD K1
2073  3111           DCA HOLDWD       /HOLDWD=2DASHAV
2074  1111           TAD HOLDWD
2075  3102           DCA PX           /STORE IN PX
2076  7120           STL
2077  1044           TAD WDREG
2100  7004           RAL
2101  3044           DCA WDREG        /PUT 1 IN WDREG
2102  1111           TAD HOLDWD
2103  7012           RTR
2104  7010           RAR
2105  0135           AND K777         /COMPUTE
2106  3113           DCA TEMP         /NEW
2107  1105           TAD DASHAV       /DASHAV
2110  7012           RTR              /AVERAGE
2111  7010           RAR
2112  0135           AND K777
2113  7041           CIA
2114  1113           TAD TEMP
2115  1105           TAD DASHAV
2116  3105           DCA DASHAV       /NEW AVERAGE
2117  5343           JMP PAVGCP
2120  7200  PDOT,    CLA
2121  3102           DCA PX           /CLEAR PX
2122  7100           CLL
2123  1044           TAD WDREG
2124  7004           RAL
2125  3044           DCA WDREG        /PUT 0 IN WDREG
2126  1111           TAD HOLDWD
2127  7012           RTR
2130  7010           RAR
2131  0135           AND K777
2132  3113           DCA TEMP         /DOTAV
2133  1104           TAD DOTAV        /AVERAGE
2134  7012           RTR
2135  7010           RAR
2136  0135           AND K777
2137  7041           CIA
2140  1113           TAD TEMP
2141  1104           TAD DOTAV
2142  3104           DCA DOTAV        /NEW AVERAGE
2143  7100  PAVGCP,  CLL              /COMPUTE
2144  1104           TAD DOTAV
2145  7010           RAR
2146  7100           CLL
2147  1105           TAD DASHAV       /NEW PAVG
```

```
2150  7010           RAR
2151  3106           DCA PAVG          /NEW AVERAGE
2152  5473           JMP I PRCAG0


                /
                /
                     *2200
2200  7200  ICODE,   CLA
2201  1021           TAD NUM           /COMPUTE
2202  7041           CIA               /INTERNAL
2203  1121           TAD K13           /CODE
2204  3210           DCA SHFTN         /WORD
2205  7621           CAM
2206  1044           TAD WOREG
2207  7413           SHL
2210  0000  SHFTN,   0
2211  1021           TAD NUM
2212  3046           DCA CODE          /STORE IT
2213  5472           JMP I ASC0
2214  7200  EFL1,    CLA
2215  2122           ISZ M2            /FIRST TIME?
2216  5246           JMP EFL11         /YES
2217  7200           CLA               /NO SECOND
2220  3036           DCA EFLAG1        /RESET EFLAG1
2221  1077           TAD M1
2222  3136           DCA PAST          /RESET PAST
2223  1032           TAD K577
2224  3013           DCA WORD          /RESET WORD
2225  1032           TAD K577
2226  3012           DCA STORE         /RESET STORE
2227  1026           TAD KCLR
2230  3532           DCA I CONDI0      /RESET CLR INST
2231  1123           TAD KM2
2232  3122           DCA M2            /RESET M2
2233  1074           TAD KLINE
2234  3075           DCA LINE          /RESET LINE
2235  3172           DCA TALLY         /RESET TALLY
2236  3173           DCA TALLY1
2237  3174           DCA TALLY2
2240  3120           DCA CWAVG
2241  3104           DCA DOTAV
2242  3105           DCA DASHAV
2243  3106           DCA PAVG
2244  4300           JMS SETPTR        /CR + 2 LFS
2245  5526           JMP I RSTAR0      /RESTART PROG
2246  1123  EFL11,   TAD KM2
2247  3412           DCA I STORE       /PUT LW SP IN ST
2250  5473           JMP I PRCAG0      /PRINT LAST CH
2251  7200  EFL2,    CLA
2252  2122           ISZ M2            /FIRST TIME?
2253  5246           JMP EFL11         /YES
2254  6141  DIAL,    LINC              /NO
```

```
                        LMODE
0255  0011              CLR
0256  0001              AXO             /CLEAR FLAGS
0257  0602              LIF 2
0260  6016              JMP 16
                        SEGMNT 2
                        *16
0016  0701              0701
0017  7300              7300            /RTN TO DIAL
                        PMODE
            /
            /
            /
                        *2300
2300  0000  SETPTR,     0

2301  7200              CLA
2302  1115              TAD K215
2303  4311              JMS TYPE        /CR
2304  1116              TAD K212
2305  4311              JMS TYPE        /LF
2306  1116              TAD K212
2307  4311              JMS TYPE        /LF
2310  5700              JMP I SETPTR
2311  0000  TYPE,       0
2312  6041              TSF
2313  5312              JMP .-1
2314  6046              TLS             /PRINT CH
2315  7200              CLA
2316  5711              JMP I TYPE
            /
            /
            /
            /
            /  INITIAL DATA PROCESSING ROUTINE
            /
            /
                        *2400
2400  0000  IPROC,      0
2401  1127              TAD K6000
2402  3011              DCA SIGNAL      /RESET SIGNAL
2403  6001              ION             /INTERUPT ON
2404  7200  IPRTN,      CLA
2405  1013              TAD WORD
2406  1376              TAD M741
2407  7650              SNA CLA         /38 WORDS YET?
2410  5365              JMP IPEXIT      /YES
2411  1012              TAD STORE       /NO
2412  7041              CIA
2413  1013              TAD WORD
2414  7640              SZA CLA         /WORD = STORE?
2415  5222              JMP .+5         /NO
```

```
2416  1037          TAD EFLAG2      /YES
2417  7440          SZA             /EFLAG2 SET?
2420  5534          JMP I DIAL0     /YES
2421  5204          JMP IPRTN       /NO.CHK AGN
2422  7200          CLA
2423  1413          TAD I WORD      /GET NEW WORD
2424  3111          DCA HOLDWD      /STORE IT
2425  1111          TAD HOLDWD
2426  7100          CLL
2427  7010          RAR
2430  7620          SNL CLA         /PULSE OR SPACE?
2431  5370          JMP GT32        /SPACE
2432  1013          TAD WORD        /PULSE
2433  1103          TAD M640
2434  7710          SPA CLA         /> 32 WORDS YET?
2435  5315          JMP IPPUL       /NO
2436  7100          CLL             /YES
2437  1111          TAD HOLDWD
2440  7010          RAR
2441  7041          CIA
2442  3113          DCA TEMP
2443  7100          CLL
2444  1106          TAD PAVG
2445  7010          RAR
2446  1113          TAD TEMP
2447  7700          SMA CLA         /DOT OR DASH?
2450  5267          JMP IPDOT       /DOT

2451  1105          TAD DASHAV      /DASH
2452  7012          RTR
2453  7010          RAR
2454  0135          AND K777        /COMPUTE
2455  7041          CIA             /NEW
2456  3113          DCA TEMP        /DASHAV
2457  1111          TAD HOLDWD      /AVERAGE
2460  7012          RTR
2461  7010          RAR
2462  0135          AND K777
2463  1113          TAD TEMP
2464  1105          TAD DASHAV
2465  3105          DCA DASHAV      /NEW AVERAGE
2466  5305          JMP IPPAV
2467  7300  IPDOT,  CLA CLL
2470  1104          TAD DOTAV
2471  7012          RTR
2472  7010          RAR             /COMPUTE
2473  0135          AND K777        /NEW
2474  7041          CIA             /DOTAV
2475  3113          DCA TEMP        /AVERAGE
2476  1111          TAD HOLDWD
2477  7012          RTR
2500  7010          RAR
```

```
2501  0135          AND K777
2502  1113          TAD TEMP
2503  1104          TAD DOTAV
2504  3104          DCA DOTAV         /NEW AVERAGE
2505  7100  IPPAV,  CLL               /COMPUTE NEW
2506  1104          TAD DOTAV         /PAVG
2507  7010          RAR
2510  7100          CLL
2511  1105          TAD DASHAV
2512  7010          RAR
2513  3106          DCA PAVG          /NEW AVERAGE
2514  5204          JMP IPRTN
2515  7300  IPPUI,  CLA CLL
2516  1111          TAD HOLDWD
2517  7010          RAR
2520  7041          CIA
2521  3113          DCA TEMP
2522  7100          CLL
2523  1106          TAD PAVG
2524  7010          RAR
2525  1113          TAD TEMP
2526  7700          SMA CLA           /DOT OR DASH?
2527  5342          JMP IPPDOT        /DOT
2530  7100          CLL               /DASH
2531  1111          TAD HOLDWD
2532  7010          RAR               /COMPUTE
2533  3113          DCA TEMP          /NEW
2534  7100          CLL               /DASHAV
2535  1105          TAD DASHAV        /AVERAGE
2536  7010          RAR
2537  1113          TAD TEMP
2540  3105          DCA DASHAV        /NEW AVERAGE
2541  5353          JMP IPPPAV
2542  7300  IPPDOT, CLA CLL
2543  1111          TAD HOLDWD        /COMPUTE
2544  7010          RAR               /NEW
2545  3113          DCA TEMP          /DOTAV
2546  7100          CLL               /AVERAGE
2547  1104          TAD DOTAV

2550  7010          RAR
2551  1113          TAD TEMP
2552  3104          DCA DOTAV         /NEW AVERAGE
2553  7100  IPPPAV, CLL
2554  1105          TAD DASHAV
2555  7010          RAR               /COMPUTE NEW
2556  3113          DCA TEMP          /PAVG
2557  7100          CLL
2560  1104          TAD DOTAV
2561  7010          RAR
2562  1113          TAD TEMP
2563  3106          DCA PAVG          /NEW AVERAGE
```

```
2564  5204            JMP IPRTN
2565  1032  IPEXIT,   TAD K577
2566  3013            DCA WORD        /RESET WORD
2567  5600            JMP I IPROC
2570  1013  GT32,     TAD WORD
2571  1103            TAD M640
2572  7710            SPA CLA         />32 WORDS YET?
2573  5204            JMP IPRTN       /NO
2574  5576            JMP I CALSP0    /YES
            /
            /
2575  7142  M636,     -636
2576  7037  M741,     -741
            /
            /
            /
            /
            /     INTERNAL TO ASCII CODE PROGRAM
            /
            /
                      *2600
2600  7000  J1,       7000
2601  6000  J2,       6000
2602  5000  J3,       5000
2603  4000  J4,       4000
2604  3000  J5,       3000
2605  2000  J6,       2000
2606  1000  J7,       1000
2607  0000  ASCII,    0
2610  7200            CLA
2611  1046            TAD CODE
2612  7700            SMA CLA
2613  5234            JMP PCODE
2614  1206            TAD J7
2615  1046            TAD CODE
2616  7700            SMA CLA
2617  5350            JMP C7000
2620  1205            TAD J6
2621  1046            TAD CODE
2622  7700            SMA CLA
2623  5333            JMP C6000
2624  1204            TAD J5
2625  1046            TAD CODE
2626  7700            SMA CLA
2627  5327            JMP C5000
2630  1203            TAD J4
2631  1046            TAD CODE
2632  7700            SMA CLA
2633  5312            JMP C4000
2634  7200  PCODE,    CLA
2635  1202            TAD J3
```

```
2636  1046           TAD CODE
2637  7700           SMA CLA
2640  5306           JMP C3000
2641  1201           TAD J2
2642  1046           TAD CODE
2643  7700           SMA CLA
2644  5271           JMP C2000
2645  1200           TAD J1
2646  1046           TAD CODE
2647  7700           SMA CLA
2650  5265           JMP C1000
2651  1465           TAD I CN5
2652  1046           TAD CODE
2653  7510           SPA
2654  5261           JMP .+5
2655  7200           CLA
2656  1047           TAD C01
2657  3010           DCA 10
2660  5464           JMP I CHKIT
2661  7200           CLA
2662  1050           TAD C02
2663  3010           DCA 10
2664  5464           JMP I CHKIT
2665  7200  C1000,   CLA
2666  1051           TAD C11
2667  3010           DCA 10
2670  5464           JMP I CHKIT
2671  7200  C2000,   CLA
2672  1466           TAD I CWAIT
2673  1046           TAD CODE
2674  7510           SPA
2675  5302           JMP  +5
2676  7200           CLA
2677  1052           TAD C21
2700  3010           DCA 10
2701  5464           JMP I CHKIT
2702  7200           CLA
2703  1053           TAD C22
2704  3010           DCA 10
2705  5464           JMP I CHKIT
2706  7200  C3000,   CLA
2707  1054           TAD C31
2710  3010           DCA 10
2711  5464           JMP I CHKIT
2712  7200  C4000,   CLA
2713  1467           TAD I CN6
2714  1046           TAD CODE
2715  7510           SPA
2716  5323           JMP .+5
2717  7200           CLA
2720  1055           TAD C41
2721  3010           DCA 10
2722  5464           JMP I CHKIT
2723  7200           CLA
```

```
2724  1056            TAD C42
2725  3010            DCA 10
2726  5464            JMP I CHKIT
2727  7200  C5000,    CLA
2730  1057            TAD C51
2731  3010            DCA 10
2732  5464            JMP I CHKIT
2733  7200  C6000,    CLA
2734  1470            TAD I CN7
```

```
2735  1046            TAD CODE
2736  7510            SPA
2737  5344            JMP .+5
2740  7200            CLA
2741  1060            TAD C61
2742  3010            DCA 10
2743  5464            JMP I CHKIT
2744  7200            CLA
2745  1061            TAD C62
2746  3010            DCA 10
2747  5464            JMP I CHKIT
2750  7200  C7000,    CLA
2751  1471            TAD I CN9
2752  1046            TAD CODE
2753  7510            SPA
2754  5361            JMP .+5
2755  7200            CLA
2756  1062            TAD C71
2757  3010            DCA 10
2760  5464            JMP I CHKIT
2761  7200            CLA
2762  1063            TAD C72
2763  3010            DCA 10
2764  5464            JMP I CHKIT
            /
            /
            /
            /
                      *3000
3000  0275  AUNK,     275
3001  7173  N3,       7173
3002  0263  A3,       263
3003  7272  ENDW,     7272
3004  0244  AENDW,    244
3005  7374  NV,       7374
3006  0326  V,        326
3007  7573  N4,       7573
3010  0264  A4,       264
3011  7770  ERR,      7770
3012  0274  AERR,     274
3013  7773  N5,       7773
3014  0265  A5,       265
```

2326	3015	7774	NH,	7774
2327	3016	0310	H,	310
2330	3017	7775	NS,	7775
2331	3020	0323	S,	323
2332	3021	7776	NI,	7776
2333	3022	0311	AI,	311
2334	3023	7777	NE,	7777
2335	3024	0305	E,	305
2336	3025	0000	SPAC,	0000
2337	3026	0240	ASPAC,	240
2340	3027	6173	N2,	6173
2341	3030	0262	A2,	262
2342	3031	6372	QM,	6372
2343	3032	0277	AQM,	277
2344	3033	6774	NF,	6774
2345	3034	0306	F,	306
2346	3035	6775	NU,	6775
2347	3036	0325	AU,	325
2350	3037	5272	PER,	5272
2351	3040	0256	APER,	256
2352	3041	5373	ENDM,	5373
2353	3042	0252	AENDM,	252
2354	3043	5773	WAIT,	5773
2355	3044	0334	AWAIT,	334
2356	3045	5774	NL,	5774
2357	3046	0314	L,	314
2360	3047	5775	NR,	5775
2361	3050	0322	R,	322
2362	3051	5776	NA,	5776
2363	3052	0301	A,	301
2364	3053	4173	N1,	4173
2365	3054	0261	A1,	261
2366	3055	4374	NJ,	4374
2367	3056	0312	J,	312
2370	3057	4774	NP,	4774
2371	3060	0320	P,	320
2372	3061	4775	NW,	4775
2373	3062	0327	W,	327
2374	3063	3373	FRAC,	3373
2375	3064	0257	AFRAC,	257
2376	3065	3374	NX,	3374
2377	3066	0330	X,	330
2400	3067	3573	DASH,	3573
2401	3070	0255	ADASH,	255
2402	3071	3773	N6,	3773
2403	3072	0266	A6,	266
2404	3073	3774	NB,	3774
2405	3074	0302	B,	302
2406	3075	3775	ND,	3775
2407	3076	0304	D,	304
2410	3077	3776	NN,	3776

```
3100 0316 N,     316
3101 3777 NT,    3777
3102 0324 T,     324
3103 2272 PAR,   2272
3104 0251 APAR,  251
3105 2374 NY,    2374
3106 0331 Y,     331
3107 2572 SCOL,  2572
3110 0273 ASCOL, 273
3111 2774 NC,    2774
3112 0303 C,     303
3113 2775 NK,    2775
3114 0313 K,     313
3115 1374 NQ,    1374
3116 0321 Q,     321
3117 1472 COMM,  1472
3120 0254 ACOMM, 254
3121 1773 N7,    1773
3122 0267 A7,    267
3123 1774 NZ,    1774
3124 0332 AZ,    332
3125 1775 NG,    1775
3126 0307 G,     307
3127 1776 NM,    1776
3130 0315 M,     315
3131 0173 N0,    0173
3132 0260 A0,    260
3133 0373 N9,    0373
3134 0271 A9,    271
3135 0772 COL,   0772
3136 0272 ACOL,  272
3137 0773 N8,    0773
3140 0270 A8,    270
```

```
3141 0775 NO,    0775
3142 0317 O,     317
          /
          /
          /
          /
                 *3200
3200 7772 UNK,   7772
3201 7772 UNK1,  7772
3202 7200 CHCK,  CLA
3203 1410        TAD I 10
3204 1046        TAD CODE
3205 7450        SNA
3206 5214        JMP .+6
3207 1410        TAD I 10
3210 2201        ISZ UNK1
3211 7410        SKP
3212 5216        JMP UNK2
```

```
2474    3213  5202          JMP CHCK
2475    3214  1410          TAD I 10
2476    3215  5224          JMP ATSF
2477    3216  7200  UNK2,   CLA
2500    3217  1172          TAD TALLY
2501    3220  7001          IAC
2502    3221  3172          DCA TALLY
2503    3222  4562          JMS I UNKCH0
2504    3223  1447          TAD I C01
2505    3224  6041  ATSF,   TSF
2506    3225  5224          JMP .-1
2507    3226  6046          TLS
2510    3227  3350          DCA SPACHK      /STORE ASCII CH
2511    3230  3021          DCA NUM         /CLEAR NUM
2512    3231  1154          TAD KSTOR
2513    3232  3014          DCA STORIT      /RESET STORIT
2514    3233  3044          DCA WDREG       /CLEAR WDREG
2515    3234  1200          TAD UNK
2516    3235  3201          DCA UNK1
2517    3236  1076          TAD IWFLAG
2520    3237  7650          SNA CLA         /IWFLAG SET?
2521    3240  5323          JMP LNCK        /NO
2522    3241  1076          TAD IWFLAG      /YES
2523    3242  3150          DCA IWF1        /STORE SPACE
2524    3243  3076          DCA IWFLAG      /CLEAR IWFLAG
2525    3244  2075          ISZ LINE        /END OF PTR LNE?
2526    3245  5247          JMP .+2         /NO
2527    3246  5325          JMP RSLN        /YES
2530    3247  1350          TAD SPACHK
2531    3250  1351          TAD MI
2532    3251  7650          SNA CLA         /ASCII = I?
2533    3252  5277          JMP CHORWD      /YES
2534    3253  1350          TAD SPACHK      /NO
2535    3254  1352          TAD MJ
2536    3255  7650          SNA CLA         /ASCII = J?
2537    3256  5277          JMP CHORWD      /YES
2540    3257  1350          TAD SPACHK      /NO
2541    3260  1353          TAD MQ
2542    3261  7650          SNA CLA         /ASCII = Q?
2543    3262  5277          JMP CHORWD      /YES
2544    3263  1350          TAD SPACHK      /NO
2545    3264  1354          TAD MU
2546    3265  7650          SNA CLA         /ASCII = U?
2547    3266  5277          JMP CHORWD      /YES
2550    3267  1350          TAD SPACHK      /NO

2551    3270  1355          TAD MV
2552    3271  7650          SNA CLA         /ASCII = V?
2553    3272  5277          JMP CHORWD      /YES
2554    3273  1350          TAD SPACHK      /NO
2555    3274  1356          TAD MZ
2556    3275  7640          SZA CLA         /ASCII = Z?
```

```
3276  5313             JMP ITSOK        /NO
3277  7100   CHORWD,   CLL              /YES
3300  1110             TAD SAFUDG
3301  1106             TAD PAVG
3302  7010             RAR
3303  3113             DCA TEMP
3304  7100             CLL
3305  1150             TAD IWF1
3306  7010             RAR
3307  7041             CIA
3310  1113             TAD TEMP         /SPACE > SADOT
3311  7700             SMA CLA          /  + PAVG?
3312  5330             JMP UNKFLG       /NO. OMIT SPACE
3313  2075   ITSOK,    ISZ LINE         /YES.  PRNT SPACE
3314  7410             SKP
3315  5325             JMP RSLN
3316  1114             TAD K240
3317  6041             TSF
3320  5317             JMP .-1
3321  6046             TLS              /PRINT SPACE
3322  5330             JMP UNKFLG
3323  2075   LNCK,     ISZ LINE         /END OF PTR LNE?
3324  5330             JMP UNKFLG       /NO
3325  4442   RSLN,     JMS I SETPT0     /YES, CR + 2 LFS
3326  1074             TAD KLINE
3327  3075             DCA LINE         /RESET LINE
3330  7200   UNKFLG,   CLA
3331  1155             TAD UNFLG
3332  7650             SNA CLA          /IN ERROR RTNE?
3333  5336             JMP .+3          /NO
3334  2161             ISZ ERWDNM       /YES. 2ND WD PTD?
3335  5343             JMP .+6          /NO
3336  3155             DCA UNFLG        /YES.  RST UNFLG
3337  3156             DCA UNCK1        /RESET
3340  3157             DCA UNCK2        /RESET
3341  3160             DCA UNCK3        /RESET
3342  5473             JMP I PRCAG0     /RETURN
3343  1177             TAD CDE32
3344  3046             DCA CODE         /GET 2ND WORD
3345  1151             TAD IWF2
3346  3076             DCA IWFLAG       /RESTORE IWFLAG
3347  5472             JMP I ASC0       /PRINT 2ND WORD
                 /
3350  0000   SPACHK,   0
3351  7467   MI,       -311
3352  7466   MJ,       -312
3353  7457   MQ,       -321
3354  7453   MU,       -325
3355  7452   MV,       -326
3356  7446   MZ,       -332
                 /
                 /
                 /
                 /
```

```
                    /       ERROR CHECKING ROUTINE
                    /

                    /
                    /  1.  ELIMINATE EXTREMELY SMALL DOTS
                    /      DUE TO NOISY TRANSMISSION.
                    /
                    /  2.  CORRECT RUN-ON CHARACTERS DUE TO
                    /      TOO SMALL AN INTER CHARACTER SPACE
                    /      BY DESIGNATING THE LARGEST OF THE
                    /      INTRA CHARACTER SPACES AS AN INTER
                    /      CHARACTER SPACE.
                    /
                    /
                            *3400
      3400  0000  UNKCHK,  0
      3401  7300           CLA CLL
      3402  1156           TAD UNCK1
      3403  7650           SNA CLA          /UNCK1 SET?
      3404  5214           JMP UNCK10       /NO.  DO CHECK
      3405  1157           TAD UNCK2        /YES
      3406  7650           SNA CLA          /UNCK2 SET?
      3407  5225           JMP UNCK20       /NO.  DO CHECK
      3410  1160           TAD UNCK3        /YES
      3411  7650           SNA CLA          /UNCK3 SET?
      3412  5312           JMP UNCK30       /NO.  DO CHECK
      3413  5600           JMP I UNKCHK     /YES.  RETURN
      3414  1173  UNCK10,  TAD TALLY1
      3415  7001           IAC
      3416  3173           DCA TALLY1
      3417  1021           TAD NUM
      3420  1354           TAD M11
      3421  7700           SMA CLA          /NUM > 8?
      3422  5600           JMP I UNKCHK     /YES.  PRT ERROR
      3423  7001           IAC              /NO
      3424  3156           DCA UNCK1        /SET UNCK1 FLAG
      3425  1174  UNCK20,  TAD TALLY2
      3426  7001           IAC
      3427  3174           DCA TALLY2
      3430  1154           TAD KSTOR
      3431  3014           DCA STORIT       /RESET MEM LOC
      3432  1021           TAD NUM
      3433  7041           CIA
      3434  3164           DCA MNUM
      3435  1104           TAD DOTAV
      3436  7012           RTR
      3437  0101           AND K1777
      3440  7041           CIA
      3441  3355           DCA PULCHK       /LOWER DOT TIME
      3442  1414  UNCAGN,  TAD I STORIT     /GET NEXT PULSE
      3443  7100           CLL
      3444  7010           RAR
```

```
3445  1355           TAD PULCHK
3446  7710           SPA CLA          /PULSE < LIMIT?
3447  5257           JMP ELIM         /YES
3450  2164           ISZ MNUM         /NO. LAST PULSE?
3451  5255           JMP .+4          /NO
3452  7001           IAC              /YES
3453  3157           DCA UNCK2        /SET UNCK2 FLAG
3454  5312           JMP UNCK30       /GO TO NXT CHECK
3455  2014           ISZ STORIT       /INC MEM LOC
3456  5242           JMP UNCAGN       /CHECK NXT PULSE
3457  1164  ELIM,    TAD MNUM
3460  3113           DCA TEMP
3461  1044           TAD WDREG        /GET BAD WORD
3462  7010           RAR
3463  2113           ISZ TEMP         /ERROR IN LINK?
3464  5262           JMP .-2          /NO
3465  3163           DCA TEMPMN       /YES. STORE
3466  5566           JMP I FIG10
3467  7300  RFIG1,   CLA CLL
3470  1021           TAD NUM
3471  1077           TAD M1
3472  3021           DCA NUM
3473  1021           TAD NUM
3474  7041           CIA
3475  1121           TAD K13
3476  3302           DCA SHFTN1
3477  7621           CAM
3500  1163           TAD TEMPMN
3501  7413           SHL
3502  0000  SHFTN1,  0
3503  1021           TAD NUM
3504  3046           DCA CODE         /CORRECTED WORD
3505  7001           IAC
3506  3157           DCA UNCK2        /SET UNCK2 FLAG
3507  7001           IAC
3510  3160           DCA UNCK3        /SET UNCK3 FLAG
3511  5472           JMP I ASC0       /PRINT NEW WORD
3512  1154  UNCK30,  TAD KSTOR
3513  1100           TAD K1
3514  3014           DCA STORIT       /SET MEM TO 1ST
3515  1021           TAD NUM          /SPACE LOCATION
3516  7041           CIA
3517  1100           TAD K1
3520  3164           DCA MNUM
3521  3353           DCA LGSPA        /SET LGSPA = 0
3522  1414  TRYAGN,  TAD I STORIT     /GET SPACE
3523  7100           CLL
3524  7010           RAR
3525  3113           DCA TEMP
3526  1113           TAD TEMP
3527  1353           TAD LGSPA
```

```
3530  7710            SPA CLA         /SPACE > LGSPA?
3531  5337            JMP SMALL       /NO
3532  1113            TAD TEMP        /YES
3533  7041            CIA
3534  3353            DCA LGSPA       /NEW LGSPA
3535  1164            TAD MNUM
3536  3165            DCA LMNUM       /LOC OF LGST SPA
3537  2014  SMALL,    ISZ STORIT      /INC MEM LOC
3540  2164            ISZ MNUM        /LAST SPACE?
3541  5322            JMP TRYAGN      /NO
3542  1165            TAD LMNUM       /YES
3543  7041            CIA
3544  3153            DCA NUM32       /LENGTH OF 2ND
3545  1165            TAD LMNUM       /WORD
3546  1021            TAD NUM
3547  3152            DCA NUM31       /LENGTH OF 1ST
3550  1044            TAD WDREG       /WORD
3551  3163            DCA TEMPMN
3552  5570            JMP I FIG20
                /
3553  0000  LGSPA,    0
3554  7767  M11,      -11
3555  0000  PULCHK,   0
                /
                /
                /
                      *3600


3600  7200  RFIG2,    CLA
3601  1152            TAD NUM31
3602  7041            CIA
3603  1121            TAD K13
3604  3210            DCA SHFTN2
3605  7621            CAM
3606  1163            TAD TEMPMN
3607  7413            SHL
3610  0000  SHFTN2,   0
3611  1152            TAD NUM31
3612  3227            DCA CDE31       /1ST CODE WORD
3613  1076            TAD IWFLAG
3614  3151            DCA IWF2        /STORE IWFLAG
3615  3076            DCA IWFLAG      /CLEAR IWFLAG
3616  1122            TAD M2
3617  3161            DCA ERWDNM      /SET WD COUNTER
3620  7001            IAC
3621  3160            DCA UNCK3       /SET UNCK3 FLAG
3622  7001            IAC
3623  3155            DCA UNFLG       /SET UNFLG FLAG
3624  1227            TAD CDE31
3625  3046            DCA CODE
3626  5472            JMP I ASC0      /PRNT 1ST WORD
                /
3627  0000  CDE31,    0
```

Appendix B

Hand-Sent Morse Code Data Plots

This appendix contains plots of hand-sent Morse code pulse and space time durations. Pulses and spaces are divided into 10 categories each for data analysis purposes. Pulses (DOTs and DASHes) are categorized by their position within a transmitted Morse code character. Spaces are categorized by the type of pulse they follow. Points contained on the individual and combined cluster plots represent time durations of all pulses and following spaces transmitted during a 10-minute period. See Chapter III for further information.

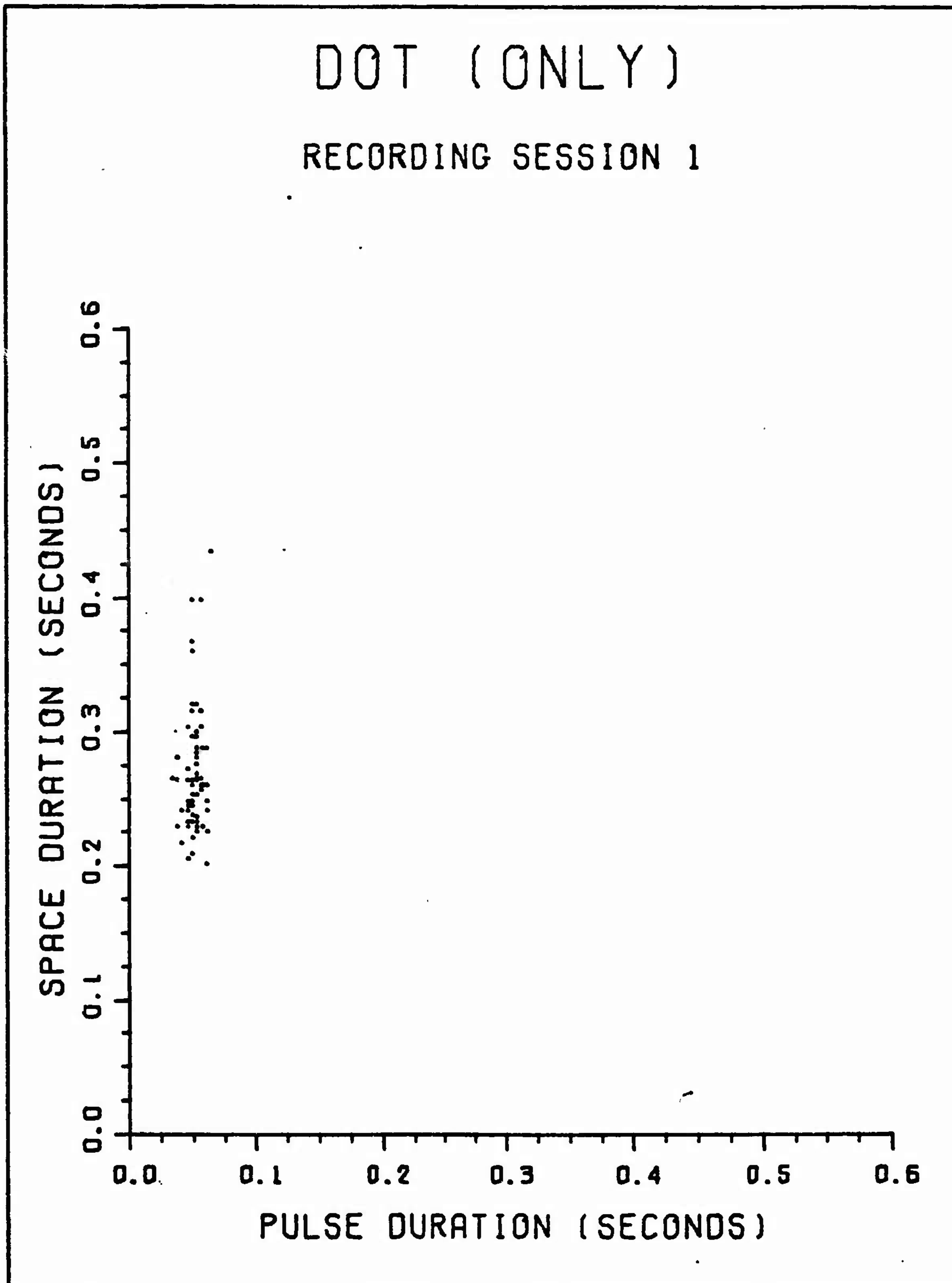


Fig. B-1. Morse Code Data Distribution Plot, DOT (Only) Time Duration vs. Time Duration of Following Space (Recording Session 1).

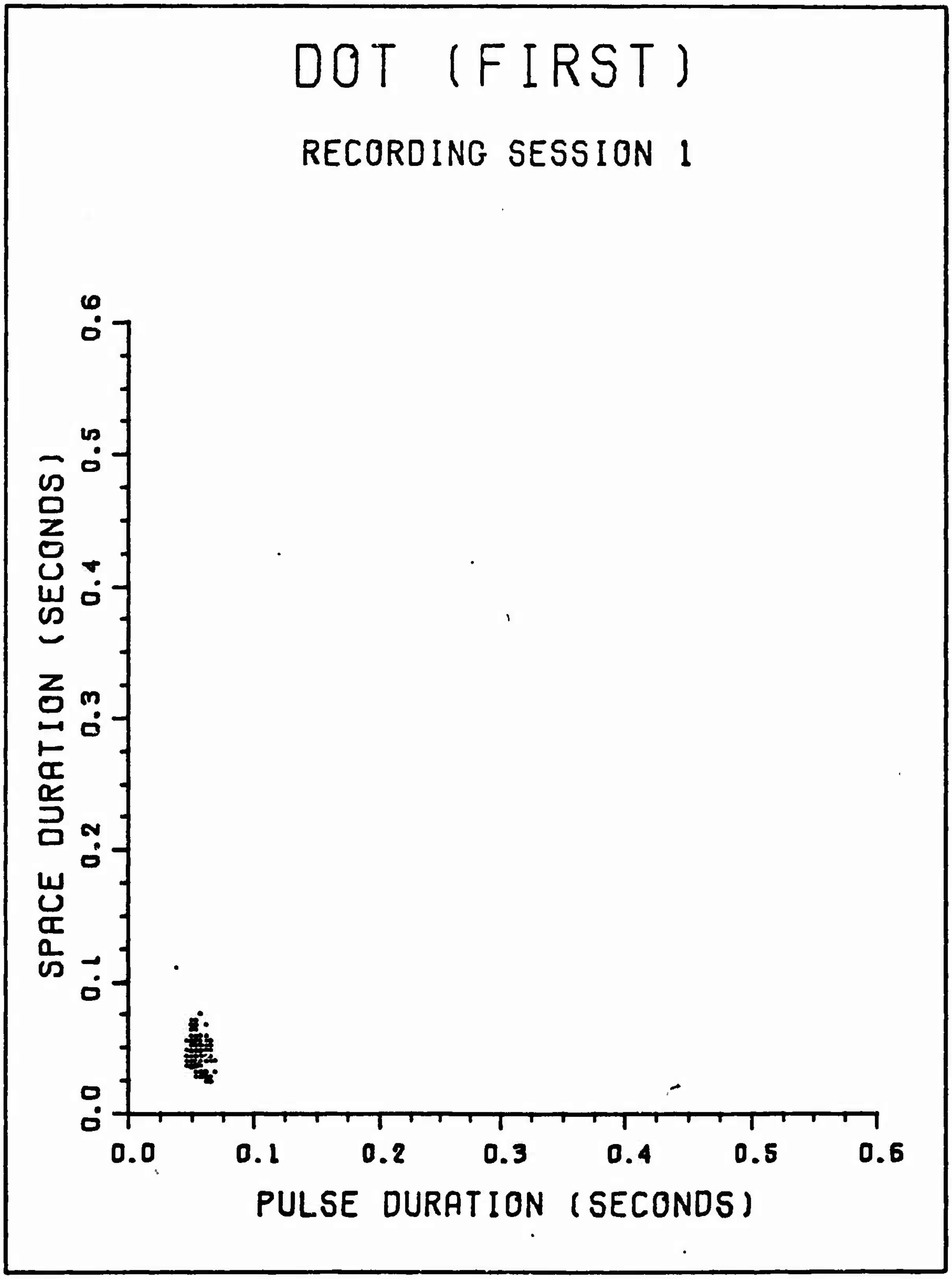


Fig. B-2. Morse Code Data Distribution Plot, DOT (First) Time Duration vs. Time Duration of Following Space (Recording Session 1).

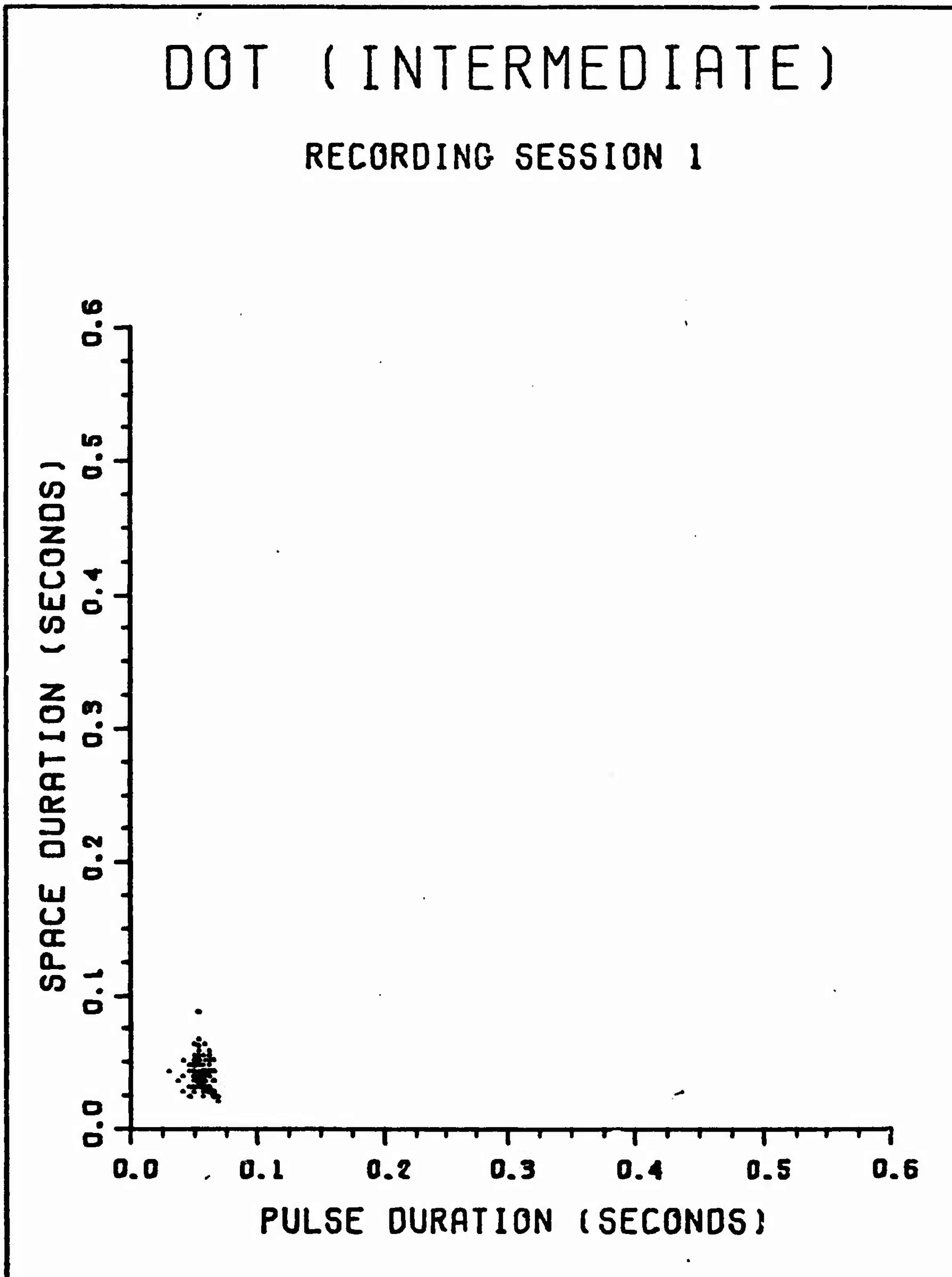


Fig. B-3. Morse Code Data Distribution Plot, DOT (Intermediate) Time Duration vs. Time Duration of Following Space (Recording Session 1).

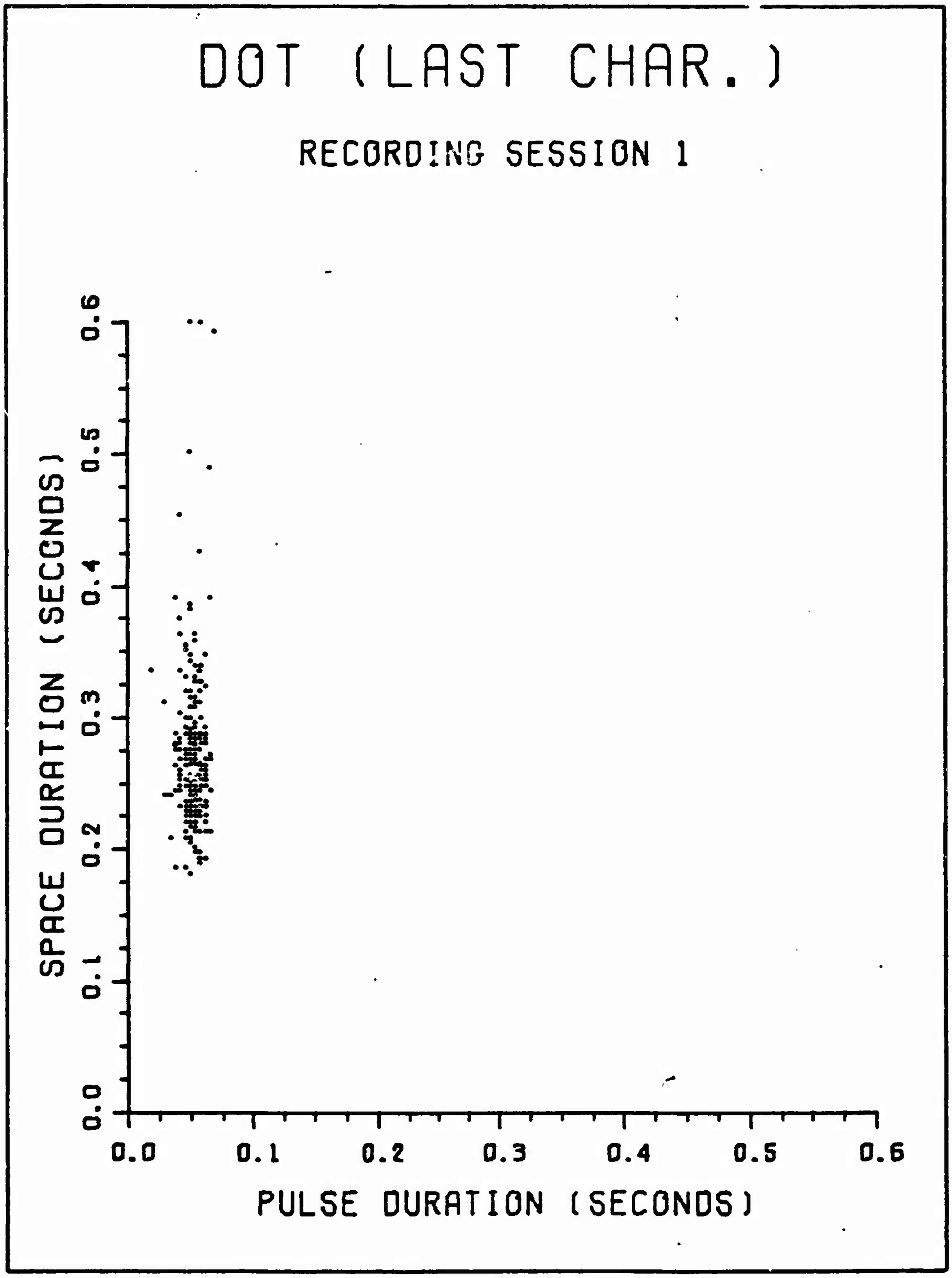


Fig. B-4. Morse Code Data Distribution Plot, DOT (Last Character) Time Duration vs. Time Duration of Following Space (Recording Session 1).

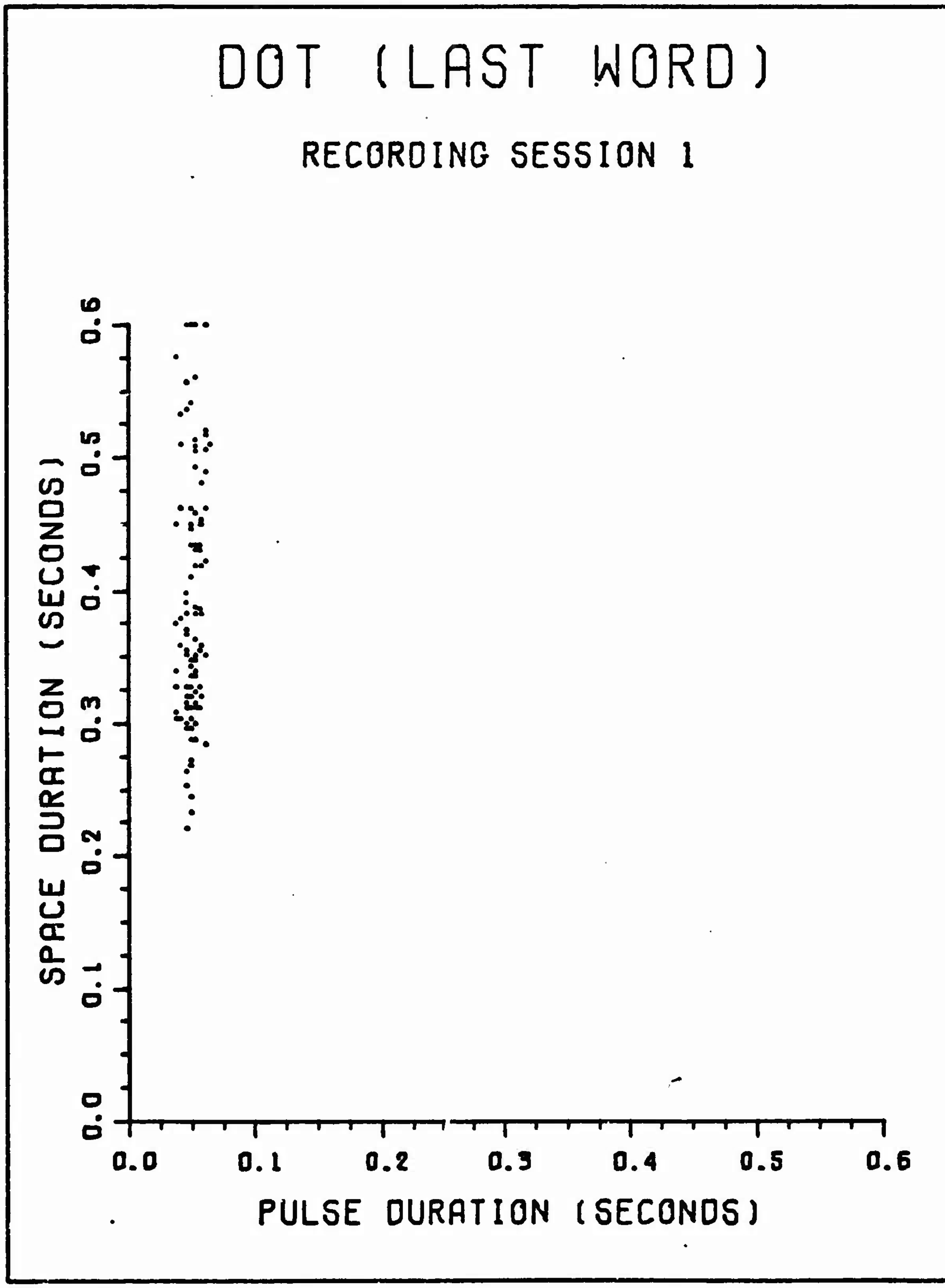


Fig. E-5. Morse Code Data Distribution Plot, DOT (Last Word) Time Duration vs. Time Duration of Following Space (Recording Session 1).

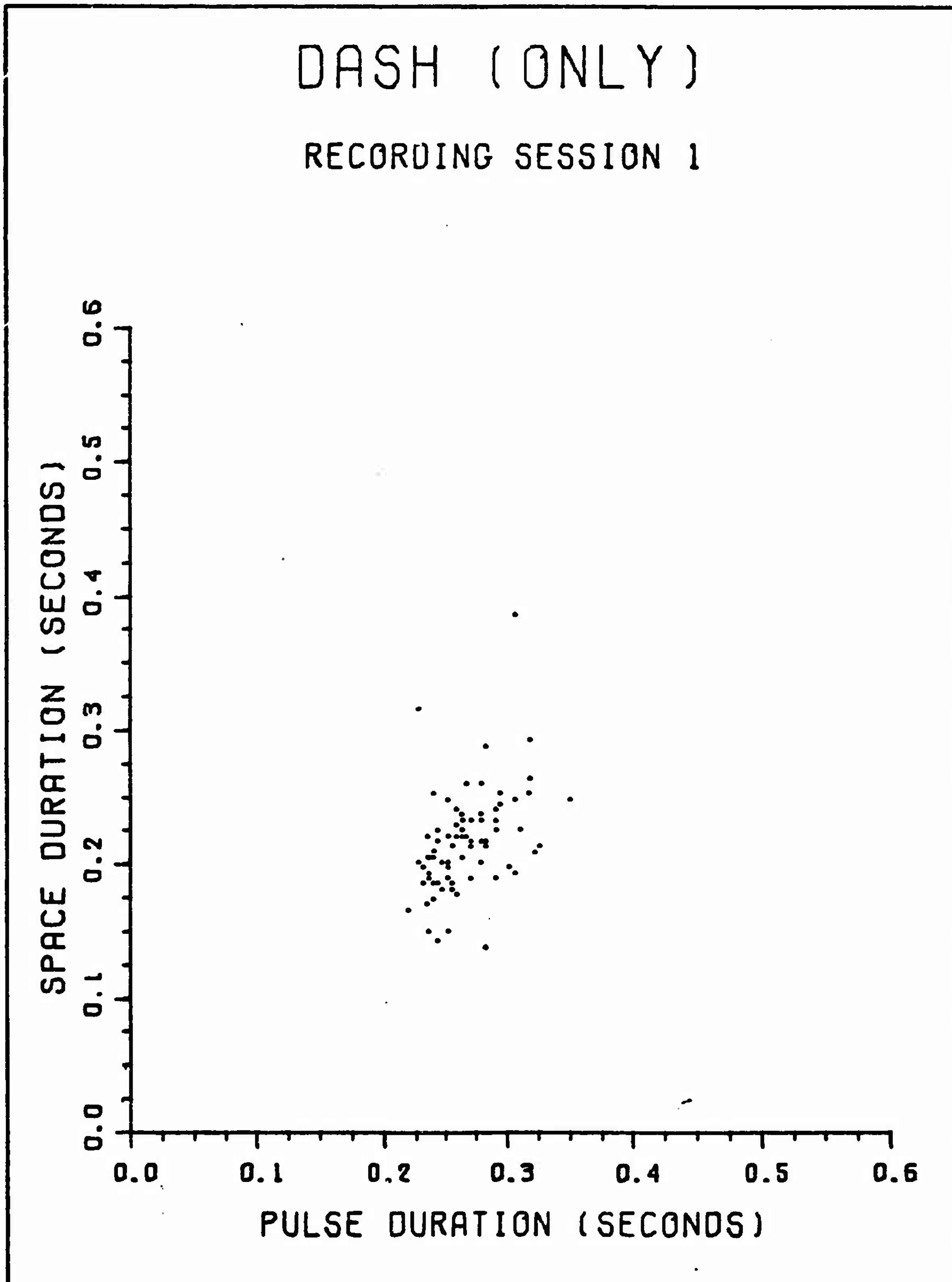


Fig. B-6. Morse Code Data Distribution Plot, DASH (Only) Time Duration vs. Time Duration of Following Space (Recording Session 1).

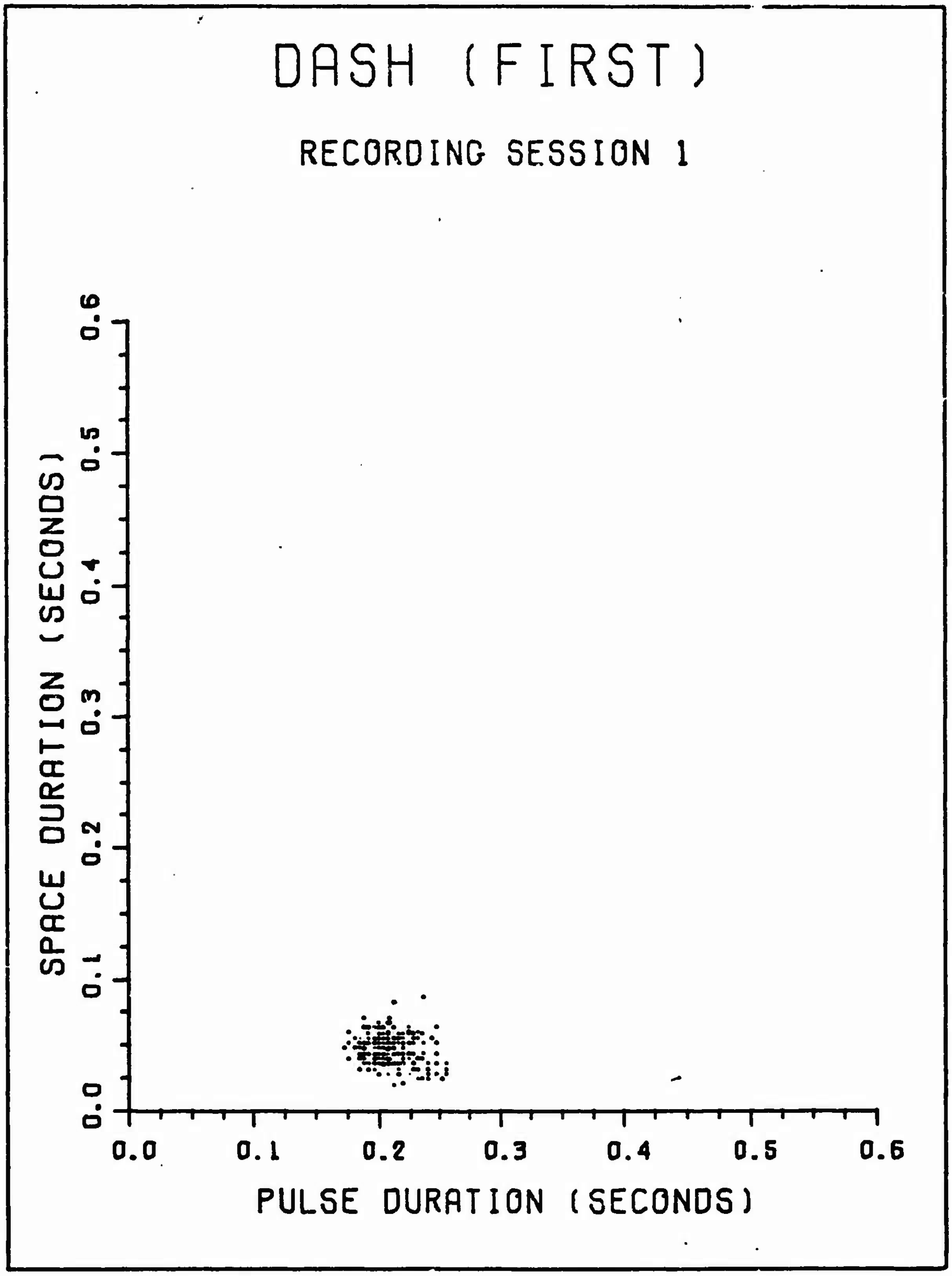


Fig. B-7. Morse Code Data Distribution Plot, DASH (First) Time Duration vs. Time Duration of Following Space (Recording Session 1).

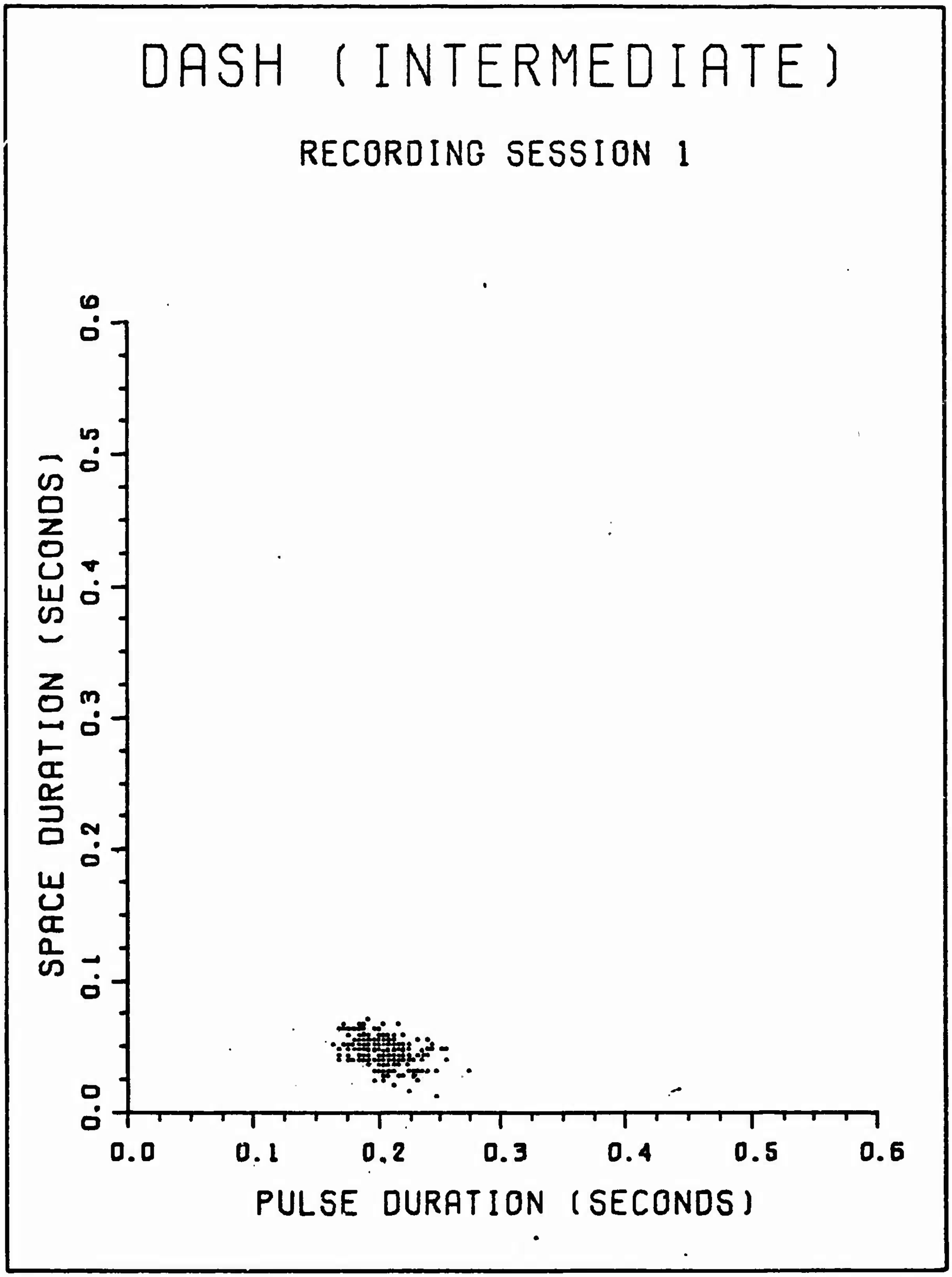


Fig. B-8. Morse Code Data Distribution Plot, DASH (Intermediate) Time Duration vs. Time Duration of Following Space (Recording Session 1).

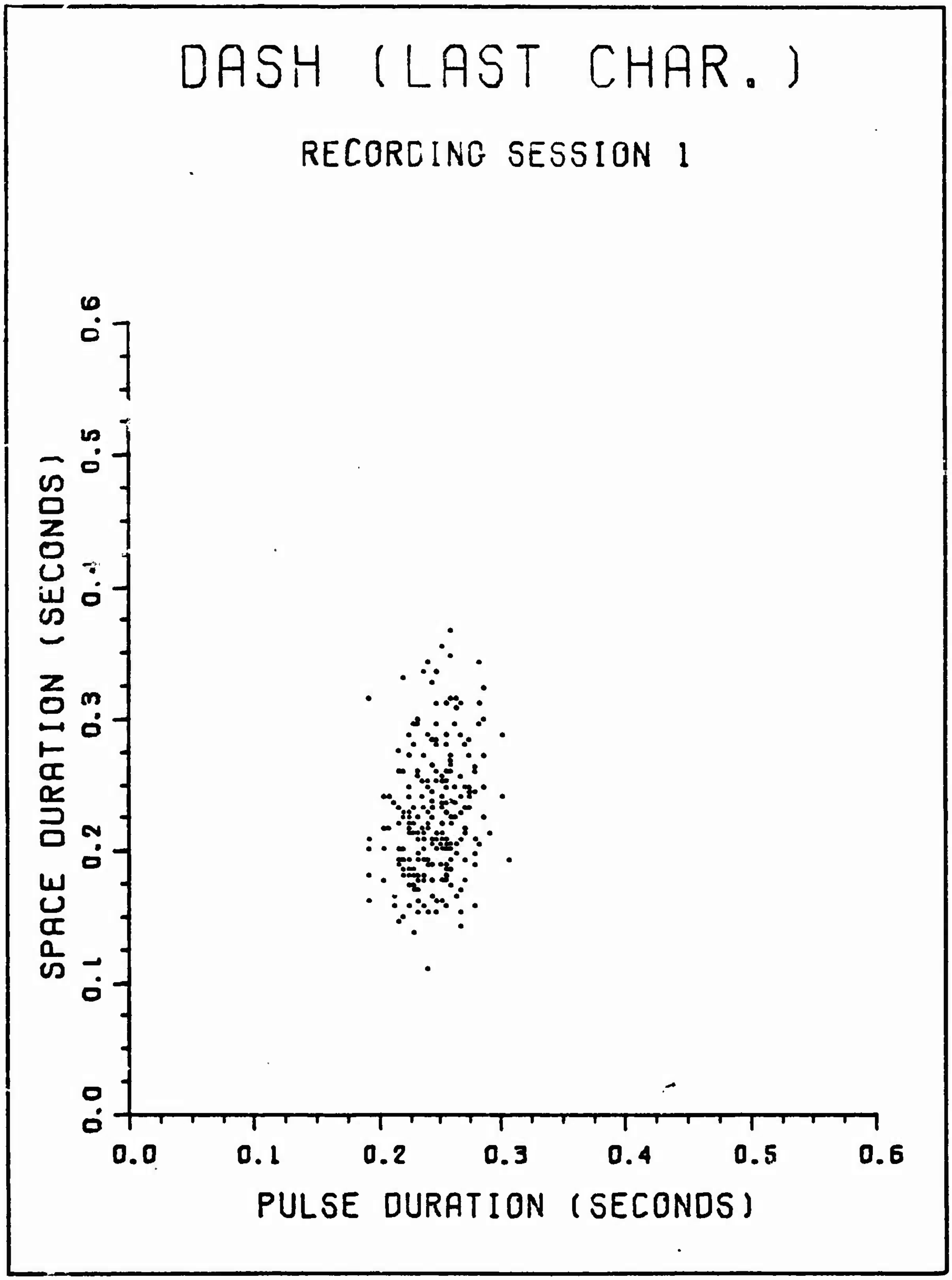


Fig. B-9. Morse Code Data Distribution Plot, DASH (Last Character) Time Duration vs. Time Duration of Following Space (Recording Session 1).

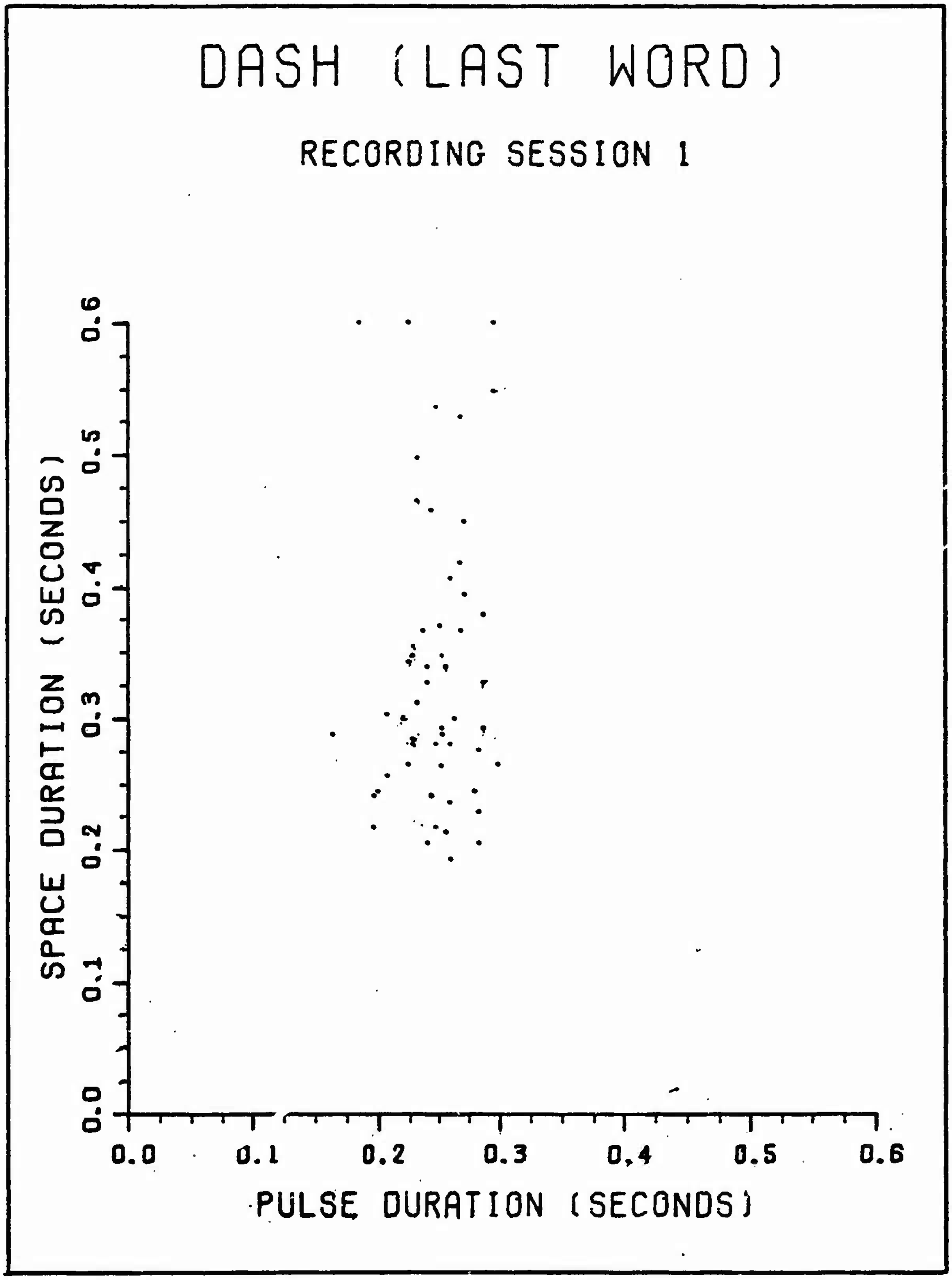


Fig. B-10. Morse Code Data Distribution Plot, DASH (Last Word) Time Duration vs. Time Duration of Following Space (Recording Session 1).

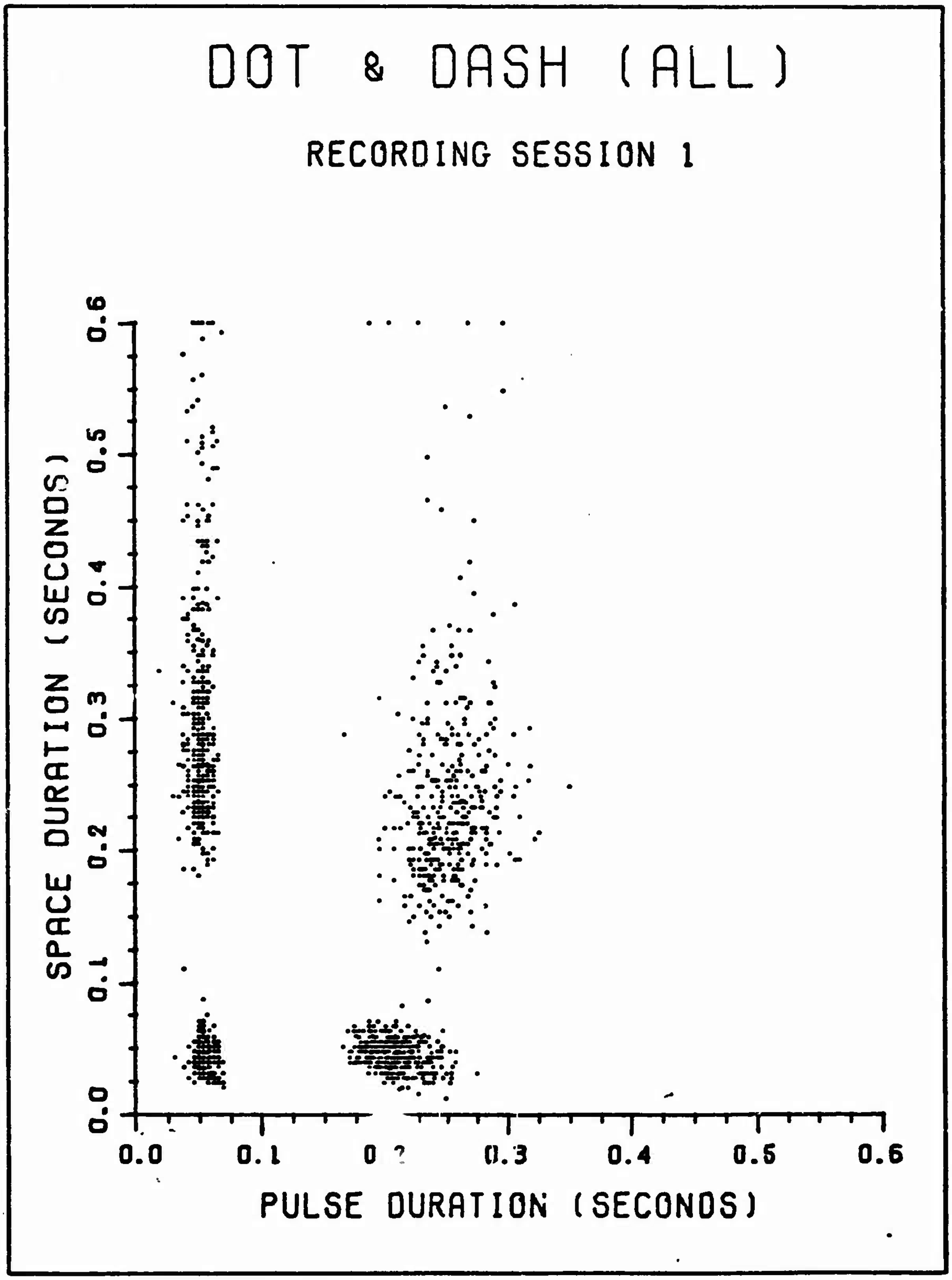


Fig. B-11. Morse Code Data Distribution Plot, Pulse Time Duration vs. Time Duration of Following Space (Recording Session 1).

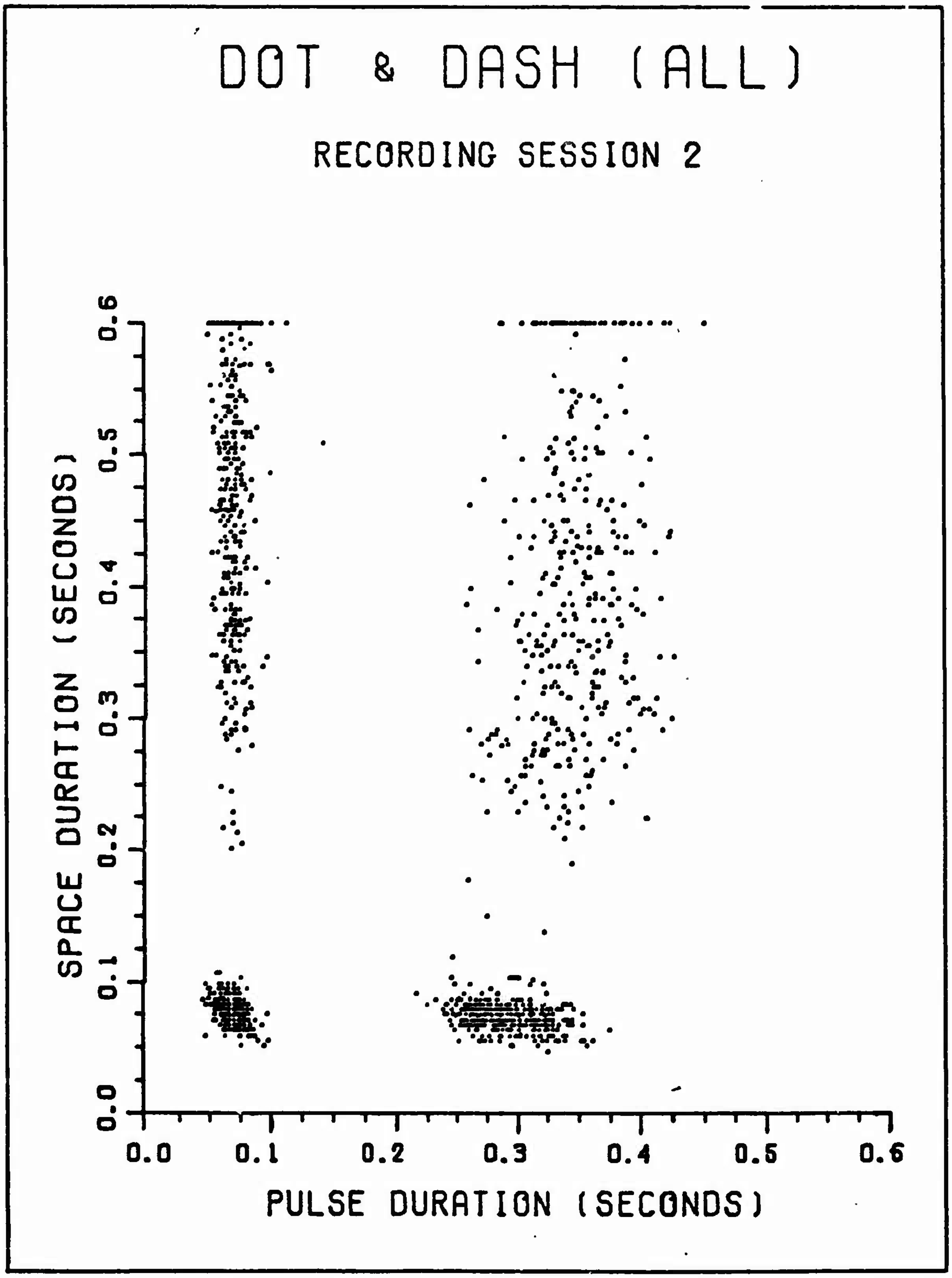


Fig. B-12. Morse Code Data Distribution Plot, Pulse Time Duration vs. Time Duration of Following Space (Recording Session 2).

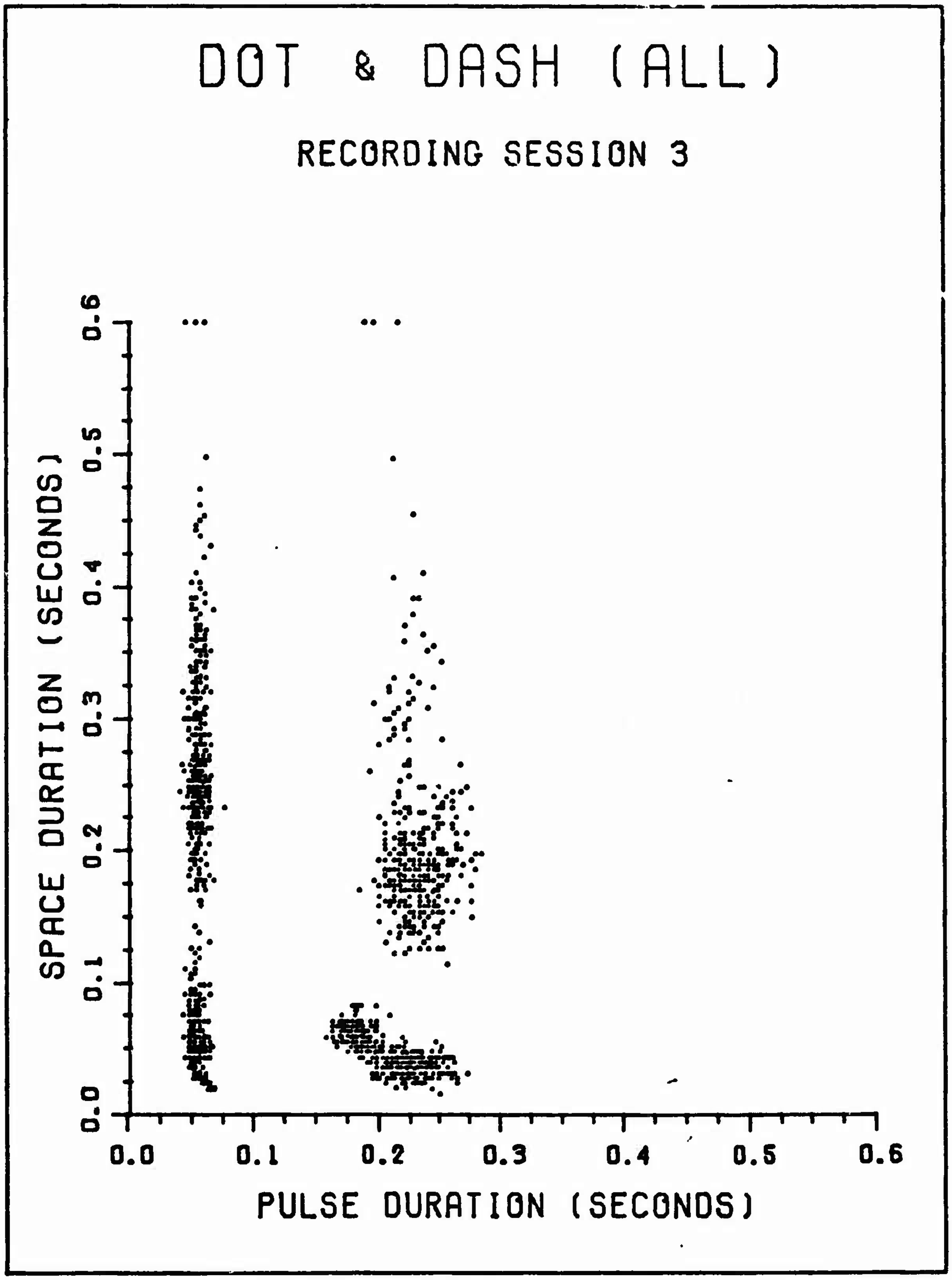


Fig. B-13. Morse Code Data Distribution Plot, Pulse Time Duration vs. Time Duration of Following Space (Recording Session 3).

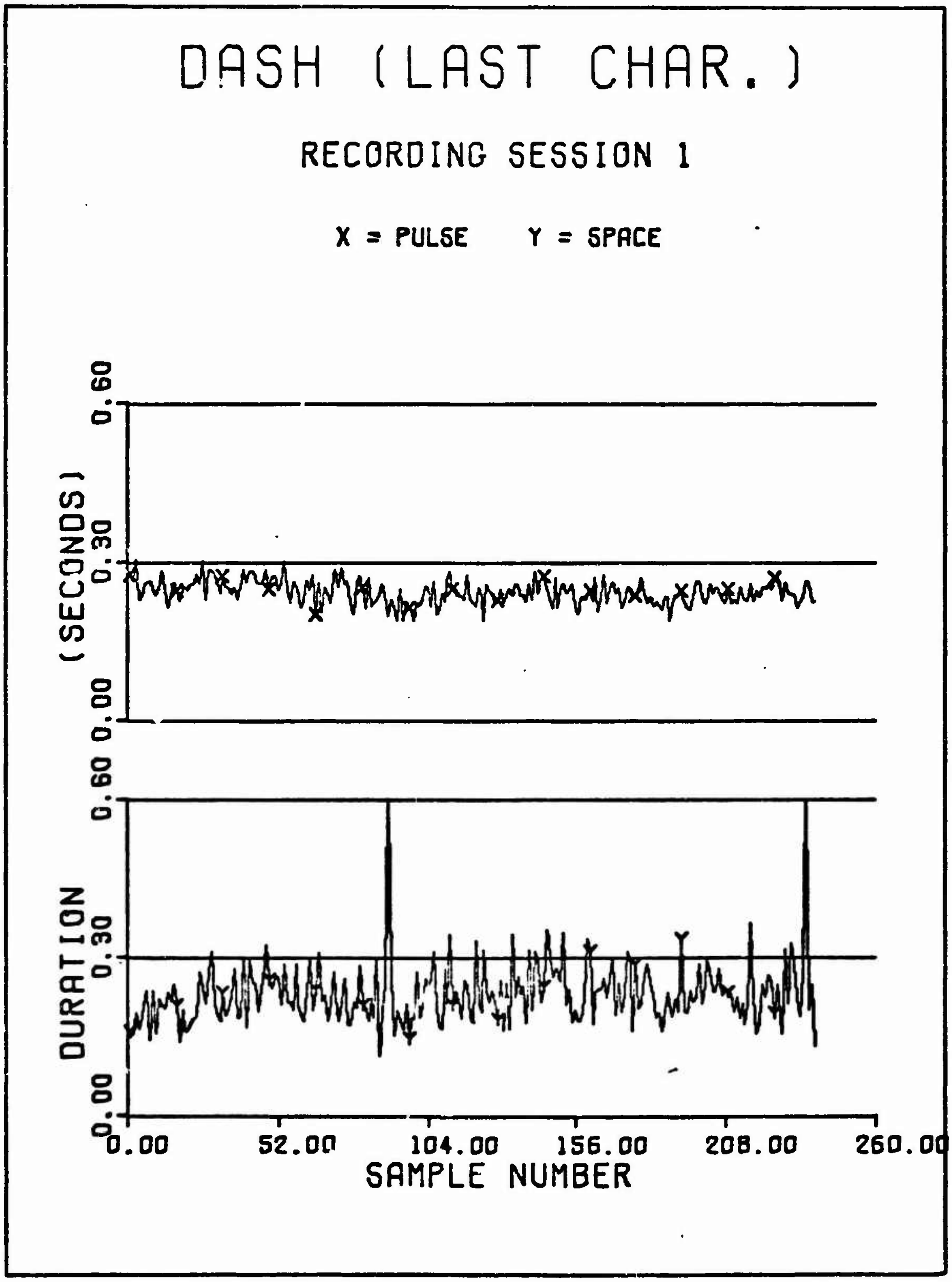


Fig. B-14. DASH (Last Character) and Following Space Time Duration Fluctuations (Recording Session 1).

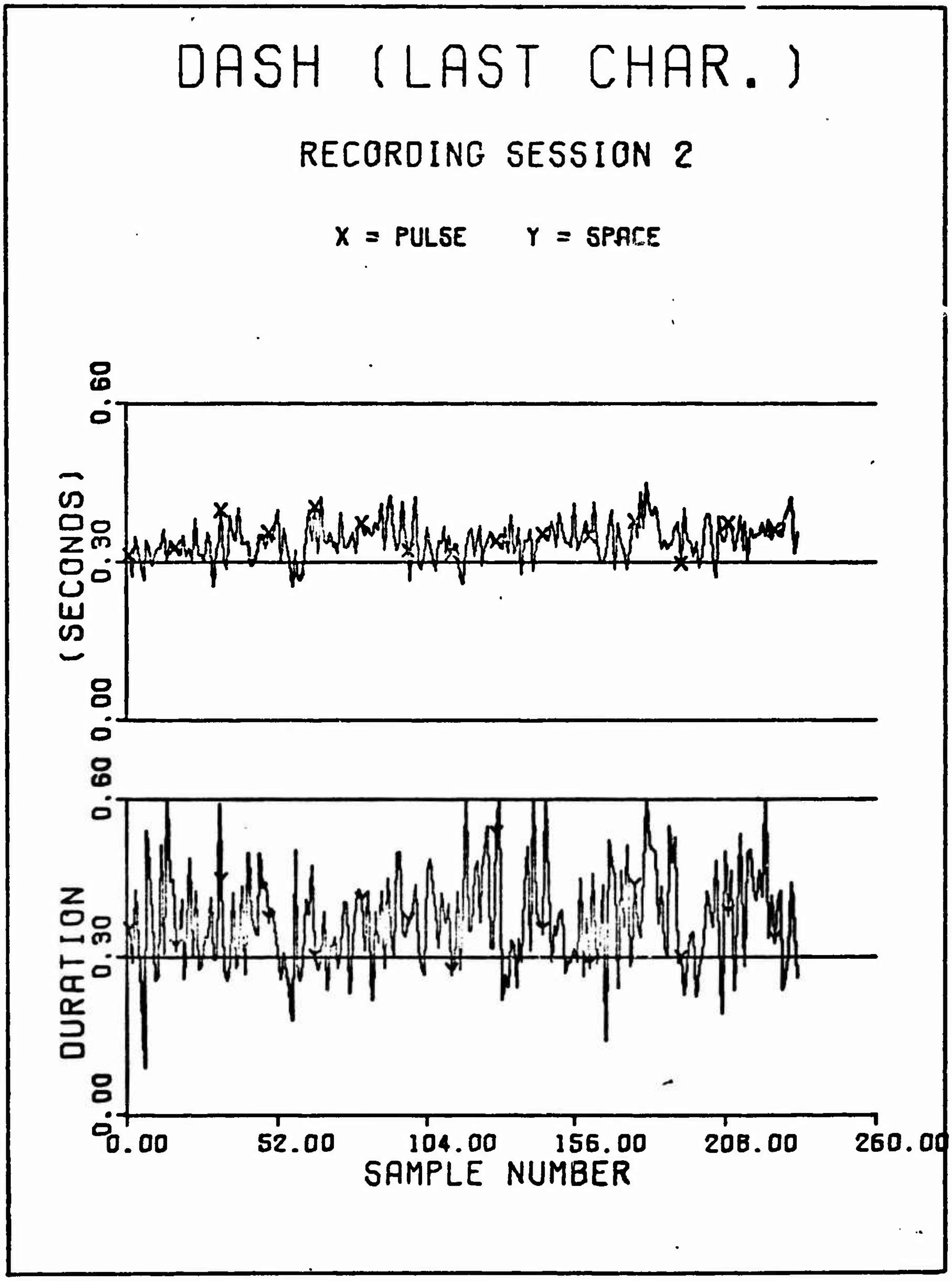


Fig. B-15. DASH (Last Character) and Following Space Time Duration Fluctuations (Recording Session 2).

Appendix C

Code and Character Listing

This appendix contains a list of 47 international Morse code characters and code representations. Corresponding internal code words and Teletypewriter output characters used in the recognition program are also listed.

Letters

Morse Character	Morse Code	Internal Code	Printer Character
A	• –	2002	A
B	– • • •	4004	B
C	– • – •	5004	C
D	– • •	4003	D
E	•	0001	E
F	• • – •	1004	F
G	– – •	6003	G
H	• • • •	0004	H
I	• •	0002	I
J	• – – –	3404	J
K	– • –	5003	K
L	• – • •	2004	L
M	– –	6002	M
N	– •	4002	N
O	– – –	7003	O
P	• – – •	3004	P
Q	– – • –	6404	Q
R	• – •	2003	R
S	• • •	0003	S
T	–	4001	T
U	• • –	1003	U
V	• • • –	0404	V
W	• – –	3003	W
X	– • • –	4404	X

Letters Cont.

Morse Character	Morse Code	Internal Code	Printer Character
Y	- • - -	5404	Y
Z	- - • •	6004	Z

Numbers

Morse Character	Morse Code	Internal Code	Printer Character
0	- - - - -	7605	0
1	• - - - -	3605	1
2	• • - - -	1605	2
3	• • • - -	0605	3
4	• • • • -	0205	4
5	• • • • •	0005	5
6	- • • • •	4005	6
7	- - • • •	6005	7
8	- - - • •	7005	8
9	- - - - •	7405	9

Punctuations and Special Functions

Morse Character	Morse Code	Internal Code	Printer Character
Period	• - • - • -	2506	.
Comma	- - • • - -	6306	,
Question Mark	• • - - • •	1406	?
Colon	- - - • • •	7006	:
Semicolon	- • - • - •	5206	;
Double Dash	- • • • -	4205	-
Parenthesis	- • - - • -	5506	)

Punctuations and Special Functions Cont.

Morse Character	Morse Code	Internal Code	Printer Character
Fraction Bar	– • • – •	4450	/
Error[a]	• • • • • • • •	0010	<
Wait	• – • • •	2005	\
End of Message	• – • – •	2405	*
End of Work	• • • – • –	0506	$
Space[b]	(none)	0000	(Space)
Unknown[b]	?	?	=

a Usually a string of 8 DOTs. May be 6 or more.

b Unique to Recognition Program.

Appendix D

Computer Test Messages

This appendix contains recognition program outputs for Recording Sessions 1 through 7. Copies of the text used to transmit Recording Sessions 1 through 4 and Recording Session 6 are also presented. Output errors (discrepancies between the text and the output) are indicated by astericks (*) and number symbols (#) located below the error. Astericks indicate errors made by the message sender; number symbols indicate errors made by the recognition program. See Table IV (Chapter VI) for recording session statistics and error percentages.

AMATEUR RADIO IS A SCIENTIFIC HOBBY, A MEANS OF GAINING PERSONAL SKILL IN THE FASCINATING ART OF ELECTRONICS AND AN OPPORTUNITY TO COMMUNICATE WITH FELLOW CITIZENS BY PRIVATE SHORT WAVE RADIO. SCATTERED OVER THE GLOBE ARE OVER 350,000 AMATEUR RADIO OPERATORS WHO PERFORM A SERVICE DEFINED IN INTERNATIONAL LAW AS ONE OF SELF TRAINING, INTERCOMMUNICATION AND TECHNICAL INVESTIGATIONS CARRIED ON BY DULY AUTHORIZED PERSONS INTERESTED IN RADIO TECHNIQUE SOLELY WITH A PERSONAL AIM AND WITHOUT PECUNIARY INTEREST. FROM A HUMBLE BEGINNING AT THE TURN OF THE CENTURY, AMATEUR RADIO HAS GROWN TO BECOME AN ESTABLISHED INSTITUTION. TODAY THE AMERICAN FOLLOWERS OF AMATEUR RADIO NUMBER OVER 250,000, TRAINED COMMUNICATORS FROM WHOSE RANKS WILL COME THE PROFESSIONAL COMMUNICATIONS SPECIALISTS AND EXECUTIVES OF TOMORROW - JUST AS MANY OF TODAYS RADIO LEADERS WERE FIRST ATTRACTED TO RADIO BY THEIR EARLY INTEREST IN AMATEUR RADIO COMMUNICATION. A POWERFUL AND PROSPEROUS ORGANIZATION NOW PROVIDES A BOND BETWEEN AMATEURS AND PROTECTS THEIR INTERESTS. AN INTERNATIONALLY RESPECTED MAGAZINE IS PUBLISHED SOLELY FOR THEIR BENEFIT. THE MILITARY SERVICES SEEK THE COOPERATION OF THE AMATEUR IN DEVELOPING COMMUNICATIONS RESERVES. AMATEUR RADIO SUPPORTS A MANUFACTURING INDUSTRY WHICH, BY THE VERY DEMANDS OF AMATEURS FOR THE LATEST AND BEST EQUIPMENT, IS ALWAYS UP TO DATE IN ITS DESIGNS AND PRODUCTION TECHNIQUES - IN ITSELF A NATIONAL ASSET. AMATEURS HAVE WON THE GRATITUDE OF THE NATION FOR THEIR HEROIC PERFORMANCES IN TIMES OF NATURAL DISASTER. TRADITIONAL AMATEUR SKILLS IN EMERGENCY COMMUNICATION ARE ALSO THE STAND BY SYSTEM FOR THE NATIONS CIVIL DEFENSE. AMATEUR RADIO IS, INDEED, A MAGNIFICENTLY USEFUL INSTITUTION.

(Sheet 1 of 2)

Fig. D-1. Prepared Text for Recording Sessions 1 through 4.

ALTHOUGH AS OLD AS THE ART OF RADIO ITSELF, AMATEUR RADIO DID NOT ALWAYS ENJOY SUCH PRESTIGE. ITS FIRST ENTHUSIASTS WERE PRIVATE CITIZENS OF AN EXPERIMENTAL TURN OF MIND WHOSE IMAGINATIONS WENT WILD WHEN MARCONI FIRST PROVED THAT MESSAGES ACTUALLY COULD BE SENT BY WIRELESS. THEY SET ABOUT LEARNING ENOUGH ABOUT THE NEW SCIENTIFIC MARVEL TO BUILD HOMEMADE SPARK TRANSMITTERS. BY 1912 THERE WERE NUMEROUS GOVERNMENT AND COMMERCIAL STATIONS, AND HUNDREDS OF AMATEURS. REGULATION WAS NEEDED, SO LAWS, LICENSES AND WAVELENGTH SPECIFICATIONS APPEARED. THERE WAS THEN NO AMATEUR ORGANIZATION NOR SPOKESMAN. BUT AS THE YEARS ROLLED ON, AMATEURS FOUND OUT HOW, AND DX JUMPED FROM LOCAL TO 500 MILE AND EVEN OCCASIONAL 1000 MILE TWO WAY CONTACTS. BECAUSE ALL LONG DISTANCE MESSAGES HAD TO BE RELAYED, RELAYING DEVELOPED INTO A FINE ART - AN ABILITY THAT WAS TO PROVE INVALUABLE WHEN THE GOVERNMENT SUDDENLY CALLED HUNDREDS OF SKILLED AMATEURS INTO WAR SERVICE IN 1917. MEANWHILE U.S. AMATEURS BEGAN TO WONDER IF THERE WERE AMATEURS IN OTHER COUNTRIES ACROSS THE SEAS AND IF, SOME DAY, WE MIGHT NOT SPAN THE ATLANTIC ON 200 METERS. MOST IMPORTANT OF ALL, THIS PERIOD WITNESSED THE BIRTH OF THE AMERICAN RADIO RELAY LEAGUE, THE AMATEUR RADIO ORGANIZATION WHOSE NAME WAS TO BE VIRTUALLY SYNONYMOUS WITH SUBSEQUENT AMATEUR PROGRESS AND SHORT WAVE DEVELOPMENT. CONCEIVED AND FORMED BY THE FAMOUS INVENTOR, THE LATE HIRAM PERCY MAXIM, ARRL WAS FORMALLY LAUNCHED IN EARLY 1914. IT HAD JUST BEGUN TO EXERT ITS FULL FORCE IN AMATEUR ACTIVITIES WHEN THE UNITED STATES DECLARED WAR IN 1917, AND BY THAT ACT SOUNDED THE KNELL FOR AMATEUR RADIO FOR THE NEXT TWO AND A HALF YEARS. THERE WERE THEN OVER 6000 AMATEURS. OVER 4000 OF THEM SERVED IN THE ARMED FORCES DURING THAT WAR.

(Sheet 2 of 2)

Fig. D-1. Prepared Text for Recording Sessions 1 through 4.

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(Sheet 1 of 3)

Fig. D-2. Recognition Program Output for Recording Session 1.

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(Sheet 2 of 3)

Fig. D-2. Recognition Program Output for Recording Session 1.

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URING THATWAR.

(Sheet 3 of 3)

Fig. D-2. Recognition Program Output for Recording Session 1.

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(Sheet 1 of 3)

Fig. D-3. Recognition Program Output for Recording Session 2.

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(Sheet 2 of 3)

Fig. D-3. Recognition Program Output for Recording Session 2.

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(Sheet 3 of 3)

Fig. D-3. Recognition Program Output for Recording Session 2.

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AMATEUR RADIO IS ASCIENTIFIC HOBBY, AMEANSOF GAINING PERSONAL
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(Sheet 1 of 3)

Fig. D-4. Recognition Program Output for Recording Session 3.

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(Sheet 2 of 3)

Fig. D-4. Recognition Program Output for Recording Session 3.

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(Sheet 3 of 3)

Fig. D-4. Recognition Program Output for Recording Session 3.

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(Sheet 1 of 3)

Fig. D-5. Recognition Program Output for Recording Session 4.

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DAY, WEMIGHTNOT SPAN THEATLANTIC ON20 0 METERS. M OS T IMPORT A
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(Sheet 2 of 3)

Fig. D-5. Recognition Program Output for Recording Session 4.

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NT OF ALL. THIS PERIODWITNESSED THEBIRTH OF THEAMERICAN RADIO RE
LAY LEAGUE , THE AMATEUR RADIO ORGANIZA TION WHOSE NAME WAS TO B
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TE DSTATES DECLAREDWAR U < WAR ET < WAR IN191 7,AND BY
  THAT ACT SOUNDED THE KNELLFORAMATEURRADIOFOR TS E N < FORTHE N
EXT TWOAND A HALF YEARS . T H ERE WE RE THEN O VE R 60 0 0AMATEU
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ORCESDURINGTHAT WAR *
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(Sheet 3 of 3)

Fig. D-5. Recognition Program Output for Recording Session 4.

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C S E R P O I M N E H O Z U P T C C X P F G C O N A Y 3 5 6 1 8
V A H G B B Z Q Q F 0 3 7 2 5 V Y Y D X 0 9 6 6 2 RT E

2 4 8 4 9 I D L K R L N W Q B E I H C D 4 2 2 5 3 I A U B T
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S H I E L D

S M O O T H I T O U T A N D T A P E I T I N P O S I T I O N
E V E R Y F O O T

(Sheet 1 of 2)

Fig. D-6. Recognition Program Output for Recording Session 5.

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1 3 2 R 5 F 3 M 0 J *

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H E A N T E T < T H E A N T E N N A I S F O R T Y O R F I F T Y
F E E T H I G H A N D W E L L I N T H E C L E A R .

W E D I S L I K E T O E X C H A N G E J O B L O T S O F S I
Z E S V A R Y I N G F R O M A Q U A R T E R U P .

D I M E N S I O N S O F T H E A N T E N N A S U I T A B L E
F O R T H E A M A T E U R B A N D S A R E G I V E N I N F I G U
R E 3 .

T H E 8 0 M E T E R A N T E N N A S H O U L D B E M A D E O F
H A R D D R A W N C O P P E R W I R E T O P R E V E N T S T R E
T C H I N G A N D S A G G I N G I N H E A V Y W I N D S .

(Sheet 2 of 2)

Fig. D-6. Recognition Program Output for Recording Session 5.

QST DE W1AW W1AW W1AW OB 450, OSCAR 309 AND APT 388 FOLLOW QST QST QST DE W1AW W1AW W1AW QST QST QST DE W1AW W1AW W1AW OB 450, OSCAR 309 AND APT 388 FOLLOW QST DE W1AW HR OFFICIAL BULLETIN NR 450 FROM ARRL HEADQUARTERS CK 92 NEWINGTON CT OCTOBER 25, 1973 TO ALL RADIO AMATEURS - NOVEMBER PRESENTS AN EXCELLENT OPPORTUNITY FOR EVERY AMATEUR TO TEST HIS FREQUENCY MEASURING SKILLS BY TAKING PART IN AN ARRL FREQUENCY MEASURING TEST. W1AW WILL TRANSMIT SIGNALS FOR MEASUREMENT ON NOVEMBER 10 AT 0230 AND 0530 GMT. THIS WILL BE THE EVENING OF NOVEMBER 9 AT 2130 EST ON APPROXIMATELY 3527 7078 AND 14079 KHZ. A SECOND SERIES OF TEST SIGNALS WILL BE TRANSMITTED THREE HOURS LATER ON ABOUT 3563 7083 AND 14072 KHZ. FULL DETAILS ON HOW TO PARTICIPATE APPEAR ON PAGE 110 OF OCTOBER QST.

Fig. D-7. Recording Session 6 Text (W1AW Bulletin).

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      QST DE W1AWA1AW W1AW OB 450, OSCAR 309 AND APT 388 FOLLT E
KST QST QST DE W1AW W1AW WAWAA E TIT QST QST DE E T1AW W1AW W1AW
OB 450, OSCAR 309 AND APT 388 =THOW ES EIE QST DE W1AW HR OFFICI
AL BULLETIN NR 450 FROM ARR\=EADQUARTERS ECK 92 NEWINGTON CT OCT
OBER 25, 1973 TO ALL RADIO AMATEURS - NOVEMBER PRESENTS AN EXCEL
LENT O=NORTUN= FOR EVERYEAMATIUR TO TEST BI_ FREQUENCY MEASURING
SKILLS BY TAKING PART IT ES NRL FREQUEND M MEASURING TEST. W1AR
TILL TRANSMIT SIGNAMRE FOWMVSUREMENT ON NO=BER 10 AT 0230 MNOE05
N0 GMT. THIS W?L BE THEETVENING OF NOVEMBIR 9 AT 2130 EST ON APP
ROXIMATELY 3527 7078 AND 14079 KHZ= II E IEEOND SEI OF TEST SIGN
ALS WILL BE TRANSMITTED THREE HOURS LATER ON ABOUT 3563 7083 AND
14072 KHZ. FULL DEA=OWN= PARTICIPATE U=PVR ON PAGE 110EOFEOCTOBE
LPTST.
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Fig. D-8. Recognition Program Output for Recording Session 6.

(8 wpm)

2 4 8 4 9 I D L K R L N W QB E IH C D 4 22 5 3 IA UB X T G L

R 0 3 3 4 3 8 M B N R A T M 0 Z I 0 3 2 0 S U C I E U J Z Y W I

E J V W D Y Z B A B 4 8 516 GZ0 T Y A S VF QC K UX K G QN S VJP

X ES C M H C D G P F H P H 5 2 4 7 1 415 5 0 F KN P Y E MR X T 1

2 6 9 1 W V Q 0 J S U L D L 7 2 6 2 8 9 F J K H E G R Q N M X Z

W 0 S T P V A U U C A F Y 3 0 7 6 1 D B G L Y E Z H K X J W R R

Q N C G V B D L X T M 0 F N S Y E Q Z B PE H JU A K I W 0 H D 1

3 0 7 6 Q Z K V S R C W M E P T X U L

(10 wpm)

E V H M X 11 3 4 0 F WIB WW 25 659 IL B ZA YFNTEEQCSP JGQGK RP

POK 25309 41687 11240 3378524996 BHFDY WCUJE IE QRXAT QIZQ T C J

SD EHLOK MG NFR UC ZBY VWACX DWGSE FXTPR OINUH VJKYA L ZB ML 09

576 05327 DIOVS YUSEK ZMFRW AHNQX 1498 6 GJPTB 09612 COMID QFPJE

LNHRK GSBVULTZA M WHEWY PYJXE K IS G T 3478 5 XVOZA 10945

(12 wpm)

R Q ZJ T S R A I 21369 DUOCG EUNDF 02589CTPBH 30258 FWMED G

XLFE 10478HYKGC IZJHB41047JZIJA KYHIZ52136 LXGKY M WFLX 85203 NV

EMW OUDNV 63025 PTCOUQSBPT 74114 RQAQS SRARQTPBSR UOC TP VIVDU96

302 WMEVN XLFWM YGKYL ZJHYR AIJZJ BHIZICGKYH 88521 79630 DFLYG E

DMWF FENVE GCOUD HBPTC IAQSB 97410 JZRQA KYSRA 69741LXTPB 58852

MWUOC NVW

Fig. D-9. Recognition Program Output for Recording Session 7.

VITA

Joel Arthur Guenther was born on [redacted], [redacted]. He graduated from high school in [redacted] and attended Newark College of Engineering from which he received the degree of Bachelor of Science in Electrical Engineering and a commission in the U.S. Air Force in 1965. He served as a Deputy Missile Combat Crew Commander and Instructor in the Minuteman II Weapon System, Malmstrom Air Force Base, from 1966 to 1969. He was then assigned as Program Manager for Minuteman I operational testing at Vandenberg Air Force Base. He entered the Air Force Institute of Technology in June 1972.

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